Deliverable Phase 2 – Climate risk assessment

Climate Resilience Enhancement in Dairy Farming (CliResDairy)

Türkiye, Aydin

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Document Information

Deliverable Title	Phase 2 – Climate risk assessment
Brief Description	This report presents the findings of the Phase 1 Climate Risk Assessment (CRA) for Aydin's dairy sector, conducted under the CliResDairy Project. It identifies key climate hazards, including extreme heat, agricultural drought, heavy rainfall, and river flooding, and assesses their impact on livestock health, milk production, and farm sustainability. The report outlines data-driven adaptation strategies, including heat stress management, efficient irrigation systems, and early warning mechanisms, to enhance climate resilience. It serves as a foundation for policy integration, stakeholder collaboration, and sustainable dairy farming practices, ensuring the long-term viability of Aydin's agricultural sector in the face of climate change.
Project name	Climate Resilience Enhancement in Dairy Farming (CliResDairy)
Country	Türkiye
Region/Municipality	Aydin
Leading Institution	Cattle Breeders' Association of Aydin
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Abbreviations and acronyms

Abbreviation / acronym	Description
AFAD	Disaster and Emergency Management Presidency
ARDSI	Agricultural and Rural Development Support Institution
CBAA	Cattle Breeders' Association of Aydin
CBAM	Carbon Border Adjustment Mechanism
CliResDairy	Climate Resilience Enhancement in Dairy Farming
CRA	Climate Risk Assessment
FAO	Food and Agriculture Organization
HSDD	Heat Stress Degree Days
IEA	International Energy Agency
GCM	General Circulation Model
RCM	Regional Climate Model
THI	Temperature-Humidity Index
TSMS	Turkish State Meteorological Service

Executive summary

This report presents the second-phase outcomes of the CLIMAAX-supported climate risk assessment (CRA) in the Aydin region, with a specific focus on the dairy sector. The assessment addresses the need for region-specific, data-driven insights into how climate-related hazards affect dairy production systems, rural livelihoods, and agricultural infrastructure. Building on the findings and workflows developed during Phase 1, this second phase enhances the spatial and thematic resolution of the analysis and supports data-informed local adaptation planning. The results aim to inform regional development strategies, agricultural policy interventions, and investment planning processes.

In Phase 2, the assessment was expanded by incorporating ensemble-based climate projections (RCP4.5 and RCP8.5), high-resolution regional datasets, and vulnerability indicators co-developed with local stakeholders. The main actions undertaken included: (i) the introduction of new sector-specific metrics such as Heat Stress Degree-Days (HSDD) and crop-level economic loss indicators; (ii) the integration of district-level exposure and vulnerability parameters, including livestock density and cooling infrastructure; and (iii) the development of localized flood risk simulations using a rain-on-grid hydrodynamic model. These efforts were supported by field visits, farm-scale validations, and participatory workshops, ensuring that the technical assessment reflected the on-ground realities of Aydın's dairy sector.

A major innovation in Phase 2 was the use of district-level dairy-specific exposure and vulnerability metrics, such as the spatial distribution of cooling infrastructure and livestock density. For instance, the risk of heat-induced milk loss was assessed by combining HSDD trends with assumptions on farm-scale ventilation fan availability. A similar approach was used to quantify fertility losses under heat stress, and to assess economic risks from agricultural drought through crop-level modeling. River flood risks were simulated using a rain-on-grid hydrodynamic model calibrated for historical and future scenarios, revealing a marked increase in flood depths and economic damage under the RCP8.5 scenario. By tailoring the CLIMAAX risk workflows to the specific context of Aydın's dairy sector and integrating local data with multi-hazard climate projections, the assessment contributes directly to the project's overarching goals: enhancing regional risk understanding, enabling evidence-based adaptation planning, and creating transferable methodologies for use in other regions. The results serve as proof of concept for how localized CRA applications can generate actionable outputs that feed into national adaptation strategies, rural development frameworks, and future CLIMAAX demonstrators.

The findings confirm that climate change will significantly intensify and compound multiple risks for dairy farming in Aydin. Heat stress already causes substantial milk and fertility losses, and this is expected to become chronic. Precipitation patterns are shifting toward shorter but more intense rainfall events, increasing the flood risk for farms situated in the Büyük Menderes Basin. Additionally, water scarcity will reduce the yields of forage crops, directly threaten feed availability and raising production costs. These projections are especially critical for small and medium-scale farms with limited adaptive capacity.

The assessment concludes that a shift from reactive to systemic risk management is urgently needed. Investments in climate-resilient infrastructure, improved irrigation systems, and data-driven early warning strategies will be essential. The final phase of the project will focus on further stakeholder engagement and supporting the integration of findings into regional adaptation and rural development policies. The final phase of the project will focus on translating these findings into concrete action. Planned activities include developing farm-level adaptation strategies,

strengthening policy alignment with regional planning efforts, and organizing a stakeholder congress to ensure wide dissemination and institutional uptake of the project outcomes.

1 Introduction

1.1 Background

Located in western Türkiye, Aydin province represents a key agricultural and livestock production area, with a particular prominence in dairy farming. The region features a diverse geography—ranging from lowland coastal areas to mountainous inland districts—and a typical Mediterranean climate marked by hot, dry summers and mild, wet winters. This climatic profile, while traditionally favorable for agriculture, has become increasingly volatile due to the accelerating impacts of climate change.

Dairy production in Aydin is a vital economic activity, involving a large number of small- and medium-scale family-run farms that are highly sensitive to climatic fluctuations. The widespread presence of high-yielding but heat-sensitive Holstein cattle has further increased the sector's vulnerability, particularly to heat stress, drought, and associated feed and water supply issues. Despite the region's productive potential, exposure to extreme temperatures, seasonal water scarcity, and increasing input costs have begun to erode the sustainability of dairy farming systems.

These challenges have underscored the urgent need for locally grounded risk assessment and adaptation planning. In this context, Aydin was selected as a pilot region under the CLIMAAX project to carry out a comprehensive, sector-specific climate risk assessment with a strong local data foundation.

1.2 Main objectives of the project

The main objective of Phase 2 of the CLIMAAX project was to move beyond a general understanding of climate risks and provide a detailed, local-scale assessment tailored to the dairy farming sector in Aydin. This phase aimed to integrate quantitative modelling with field-based insights in order to accurately map hazard, exposure, and vulnerability dynamics across the region. A particular focus was placed on evaluating how extreme heat, drought, and heavy rainfall impact milk yield, animal health, fertility, feed security, and infrastructure resilience.

To support this objective, the Cattle Breeders' Association of Aydin (CBAA), in coordination with the Provincial Directorate of Agriculture and Forestry, organized on-site visits to seven dairy farms of varying scales, as well as meetings with key local stakeholders, including Agricultural and Rural Development Support Institution (ARDSI), Yöre Yem (a regional feed producer), the Aydın Chamber of Agriculture, milk cooperatives, and individual farmers. Farm selection was guided by criteria such as production scale, infrastructure features, geographic setting, and prior exposure to climate-related hazards. These field visits played a key role in grounding the analysis in local realities, validating spatial data, and improving the contextual relevance of climate risk assessment.

In Phase 2, the CLIMAAX Handbook served as a guiding framework to transition from high-level risk screening to a targeted, sector-specific methodology. The assessment was significantly enhanced through the use of local datasets and models, including high-resolution flood depth maps, land use/land cover data, livestock distribution statistics, and farm-level THI measurements. These were combined with qualitative findings from surveys and field observations carried out by CBAA and local experts.

This integrated approach allowed for a much more accurate and locally relevant depiction of hazard conditions and exposure patterns. The combined use of the CLIMAAX Handbook and region-specific data not only improved the quality of the risk assessment but also strengthened the capacity to identify feasible and farm-level adaptation measures. As such, Phase 2 provided a solid foundation for future policy recommendations, funding applications, and institutional planning to enhance climate resilience in Aydin's dairy sector.

1.3 Project team

Project Team:

- Project Coordinator: Hediye Cerit
- Technical Department of Cattle Breeders' Association of Aydin
- External Consulting Services:
  - Assoc. Prof. Nusret Demir: Technical Advisor (Geomatics & Industrial Engineer)
  - Dr. Çağrı Karaman: Technical Advisor (International Climate Analysis and Model Development Expert)
  - M. Kemal Demirkol: Technical Advisor (Climate Adaptation, Risk Assessment)
  - Engin Koç: Technical Advisor (Climate Adaptation, Risk Assessment)
  - Elif İrem Köse Kiper: Technical Advisor

1.4 Outline of the document's structure

This section provides a structured overview of the document's contents, enabling readers to easily navigate between key components of the Climate Risk Assessment (CRA) report. The table includes all major chapters and subsections, such as the project background, assessment methodology, localized risk analysis, key findings, evaluation of adaptation capacity, and the forward-looking work plan for Phase 3. Supporting sections, including monitoring and evaluation, conclusions, and annexes, are also listed for reference. Page numbers are indicated for each item to guide the reader through the report in a logical and accessible manner.

2 Climate risk assessment – phase 2

2.1 Scoping

2.1.1 Objectives

The main goal of Phase 2 of the CLIMAAX CRA was to create a spatially detailed, sector-specific climate risk profile for Aydın's dairy sector, supporting evidence-based adaptation planning and offering actionable insights for local stakeholders and policymakers. Key outcomes include a better understanding of how heat stress, drought, flooding, and extreme rainfall affect production systems, identification of high-risk districts and vulnerable groups (especially small farms without cooling infrastructure), and development of targeted adaptation strategies that can inform regional planning and national adaptation efforts.

Despite its broad scope, the CRA faced limitations such as gaps in farm-level data (e.g., on ventilation and fertility), varying technical capacity among producers, and challenges in cross-sector coordination. To address these issues, the team combined field visits with qualitative inputs, engaged a wide range of stakeholders, and adopted a flexible, data-driven approach aligned with local realities.

2.1.2 Context

Prior to the CLIMAAX project, climate risk assessments in Aydin were largely limited to sectoral observations or short-term reactive measures in response to specific events such as droughts, heatwaves, or floods. While Türkiye's National Adaptation Strategy and Action Plan provides essential guidance at the national level, there is ongoing need to strengthen its local-level implementation, particularly in sectors such as dairy and livestock.

The CRA conducted under the CLIMAAX framework was designed to address this gap by focusing on a critical intersection of climate change, food security, and rural livelihoods. The dairy sector in Aydin faces growing challenges due to both gradual and sudden climate stressors, including rising temperatures, increased frequency and intensity of heatwaves, agricultural drought, and flood risk. These hazards affect animal health, fertility, and productivity, and also place additional stress on water resources, energy use, and farm infrastructure. These risks are further exacerbated by structural issues in the sector, such as increasing input costs, fragmented production systems, and limited adaptive capacity at the farm level.

From a governance standpoint, risk management in the region involves several public and private institutions, including the Provincial Directorate of Agriculture and Forestry, Cattle Breeders' Association of Aydin (CBAA), the Agricultural and Rural Development Support Institution (ARDSI), Regional Director of the 21st Regional Directorate of State Hydraulic Works and local municipalities. However, there is currently no fully integrated or climate-specific regional policy framework. Incentive mechanisms for adaptation—such as subsidies for cooling systems or efficient irrigation technologies—are either insufficient or not uniformly applied. In this context, the CRA provides an essential evidence base to support decision-making and contribute to the development of locally relevant adaptation strategies.

During stakeholder consultations and technical workshops, key adaptation priorities were identified across ventilation, water management, and infrastructure planning. These include enhancing barn cooling systems, particularly in small and medium-sized farms, integrating rooftop solar energy to reduce operational costs and strengthening animal health monitoring and milk quality control under extreme climate conditions. For water-related risks, proposed measures include modernizing irrigation systems, promoting drought-tolerant forage crops, and adopting solar-powered water supply for agricultural use. In flood-prone areas, relocation of high-risk farms and improved drainage were suggested.

The full list of proposed strategies, along with stakeholder feedback and implementation challenges, is provided in detail in the annexed workshop report. These outcomes collectively support a transition from reactive responses to proactive, farm-level climate resilience planning in Aydin's dairy sector.

2.1.3 Participation and risk ownership

Stakeholder involvement in Phase 2 of the CLIMAAX project was ensured through a series of participatory activities, led by CBAA in coordination with local institutions. A wide range of actors took part in the process, including local dairy producers, agricultural cooperatives, the Provincial Directorate of Agriculture and Forestry, the Agriculture and Rural Development Support Institution (ARDSI), Regional Director of the 21st Regional Directorate of State Hydraulic Works, Aydin Provincial Directorate of Meteorology, Aydin Provincial Directorate of Disaster and Emergency Management , Provincial Directorate of Environment and Climate Change, Aydin Metropolitan Municipality, academic experts from Aydin Adnan Menderes University, and private sector representatives. A total of 124 participants attended the regional stakeholder workshop held on December 24, 2025, where thematic discussions were organized around three climate hazards: heat stress, drought, and flooding[1].

Risk ownership in the region is distributed across multiple levels. The identification and assessment of climate-related risks are primarily carried out by CBAA, with technical contributions from academics and local government experts. Implementation of risk mitigation measures, however, is a shared responsibility between farmers, cooperatives, and public institutions. Entities like ARDSI and the Provincial Directorate of Agriculture play central roles in enabling adaptation investments and providing support programs.

The most vulnerable groups identified include small-scale dairy farms in high-exposure inland areas, such as Karacasu and Kuyucak, where both financial capacity and access to mechanical cooling systems remain limited. While no formal definition of acceptable risk thresholds exists, dairy producers in the region generally tolerate short-term production losses. Yet, sustained milk yield declines or fertility impairments exceeding 10–15% are considered economically unsustainable, often prompting producers to scale back or exit the sector entirely. A detailed report and the outputs of the stakeholder workshop are included in the Annex.

2.1.4 Application of principles

Throughout the Climate Risk Assessment (CRA) for Aydin, the process was designed to be scientifically sound, socially inclusive, and guided by the precautionary principle. These guiding values were integrated across all phases—from scoping to stakeholder engagement and risk evaluation—to ensure that results were both credible and locally relevant. Social justice and equity were central in identifying vulnerabilities across different farm types. The CRA recognized that small-scale, low-income, and infrastructure-poor farms face greater climate risks. This was reflected in the differentiated vulnerability profiles and stakeholder engagement strategies, with targeted inclusion of priority groups via CBAA's field network. This approach aligned with procedural and distributive justice, ensuring the perspectives of more vulnerable groups were meaningfully represented.

Quality, rigour, and transparency were upheld by applying the CLIMAAX Handbook methodology alongside localized data, including satellite observations, reanalysis datasets, and agricultural records. All assumptions were clearly documented and validated with local experts, making the analysis replicable and open to review. In line with the precautionary principle, the CRA took a conservative approach to risk evaluation, prioritizing action in the face of uncertainty. Indicators like rising heat stress and declining forage yields informed forward-looking strategies, supporting anticipatory rather than reactive adaptation planning. Together, these principles helped produce a fair, evidence-based, and flexible assessment that can support climate resilience in Aydin's dairy sector both now and in the future.

2.1.5 Stakeholder engagement

The engagement of stakeholders, experts, and priority groups was carried out through multiple channels, including a large-scale participatory workshop, structured surveys, and direct field visits. The structured surveys were conducted with CBAA field staff and agricultural representatives across

[1] Due to page limitations, a detailed description of the workshop participants, methodology, and outcomes could not be included in the main report. These details are provided separately in the annexed "CliResDairy Project Stakeholder Workshop Report". Visual documentation from the site visits and the stakeholder workshop is provided in a separate annex titled "Visual Documentation of Site Visits and the CliResDairy Project Stakeholder Workshop".

14 districts. These surveys explored the impacts of heatwaves, drought, and extreme weather on milk yield, animal fertility, feed availability, water use, and infrastructure resilience. To validate and complement these insights, field visits were carried out in August 2025 in Efeler, Koçarlı, İncirliova, and Çakırbeyli. These visits provided critical context on the condition of barns, availability of ventilation systems, feeding strategies, and climate vulnerabilities at the farm level.
After that, stakeholder engagement workshop organized in Aydin in December 2025 brought together producers, cooperatives, public institutions, researchers, and civil society actors to collectively assess the risks facing dairy farming in the region. Discussions were structured thematically and facilitated by academic and institutional moderators, providing a platform for dialogue on observed climate impacts and feasible adaptation actions.
Stakeholder engagement sessions served as a platform to share interim CRA results and gather feedback through presentations, risk maps, and open discussions. Participants largely confirmed key findings—particularly the adverse effects of heat stress on milk production and fertility, rising cooling costs, and feed availability issues. Stakeholders emphasized the importance of cooperative-based investments, better technical training on adaptation, and more accessible financing for small-scale farms. While the results were well-received and are expected to inform future planning by CBAA and relevant institutions, challenges such as limited technical capacity, reluctance to share data, and systemic barriers were also noted. A detailed account of the workshop process and outcomes is provided in the Annex.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

In Aydin's dairy sector, multiple climate hazards—especially heatwaves, agricultural drought, extreme precipitation, and river flooding—pose serious short- and long-term risks. These hazards often interact, creating compounding effects that undermine farm resilience and increase sectoral vulnerability. Currently, heatwaves and drought stand out as the most damaging. Rising summer temperatures and humidity have led to chronic heat stress in dairy cattle, reducing milk yields and increasing mortality, particularly in farms lacking proper cooling systems. At the same time, drought conditions continue to limit forage production and raise feed costs, especially for small and medium-scale farms with fewer adaptive resources.
Analysis based on the Copernicus Climate Atlas (Iturbide et al., 2022) confirms these patterns and projects a clear intensification under future climate scenarios. In high-emission pathways, daily mean temperatures in western Türkiye are expected to increase substantially, with a growing number of very hot days and nights. The projections also suggest that while average precipitation may decline or remain stable, short-duration, high-intensity rainfall events are expected to become more frequent. This dynamic will likely elevate river flooding risks in the Büyük Menderes Basin, threatening farm infrastructure and local transport routes.
As such, the CRA focused on the four priority hazards based on stakeholder feedback and scientific analysis. In Phase 2, risk analysis was enhanced with localized data and new methods, including in-house flood modeling and metrics such as Temperature–Humidity Index (THI) and Heat Stress Degree-Days (HSDD) to assess heat stress. These refinements improved the spatial and contextual accuracy of risk mapping across the province.
However, further data is still needed—particularly on soil moisture, animal health, and local hydrology—to strengthen future assessments. Ongoing collaboration with local institutions remains essential to closing these gaps and supporting targeted, risk-informed adaptation in the dairy sector.

2.2.3 Choose Scenario

Future climate conditions for the Aydin region were assessed using ensemble-based climate projections under the RCP4.5 and RCP8.5 scenarios. These scenarios were selected to capture a plausible range of future climate outcomes, from a moderate mitigation pathway (RCP4.5) to a high-emission, high-impact pathway (RCP8.5). The assessment did not explicitly model alternative future socio-economic development pathways. During stakeholder consultations, dairy farmers emphasized that near to medium-term investment decisions are largely constrained by present-day farm structures and market conditions. As a result, the analysis focuses on how future climate hazards would impact the current dairy production system. Future climate conditions and socio-economic factors were combined through a risk-based impact framework, rather than through fully integrated socio-economic scenarios.

For extreme precipitation and heatwave hazards, the assessment primarily focused on the medium-term horizon (2041–2070), which is highly relevant for dairy farm infrastructure, herd management, and investment planning. These hazards directly affect animal welfare, productivity, and operational costs within the expected lifetime of farm facilities and equipment. Agricultural drought impacts were assessed over a short-term horizon (2046–2050), reflecting near-future risks to forage and feed crop production that are already influencing farm-level decision-making and feed security. For river flooding, the analysis emphasized long-term conditions (2071–2100) under high-emission scenarios, capturing the cumulative effects of intensifying extreme precipitation on flood depths, inundation extent, and economic damages within the Büyük Menderes Basin.

2.3 Regionalized Risk Analysis

The hazard and risk analyses were refined using localized datasets obtained from relevant local and national authorities. In the extreme precipitation workflow, the spatial distribution of dairy farms was used to identify holdings potentially exposed to future heavy rainfall events. Climate model outputs were analyzed using a multi-model ensemble approach based on 44 GCM–RCM combinations, allowing climate model uncertainty to be explicitly accounted for. For the river flooding assessment, historical extreme precipitation maps were derived from long-term observational records (>40 years) from 77 meteorological stations provided by the Turkish State Meteorological Service. Theni using the calculated change in precipitation in extreme precipitation workflow, future extreme precipitation maps were prepared. A rain-on-grid hydrodynamic modelling framework was then applied to simulate flood hazards across the basin under both historical and future climate conditions. In the heatwave analysis, farm-level vulnerability was characterized by using dairy-specific indicators, including cattle numbers, the availability of cooling fans, and the spatial location of farms. For agricultural drought, the assessment relied on the spatial distribution of cultivated areas for 15 forage and food crops at the district level in Aydin, together with historical crop yields (2024) and production volumes obtained from the Provincial Directorate of Agriculture. Crop-specific producer prices were taken from 2024 FAOSTAT to support the economic impact analysis.

As part of the data collection process in Phase 2, official agricultural planning reports related to livestock and crop production were shared by the Aydin Provincial Directorate of Agriculture and Forestry. In addition, the Disaster and Emergency Management Authority (AFAD) provided historical disaster records concerning geohazards such as landslides, rockfalls, and avalanches, supporting a broader understanding of the region's past hazard exposure.

Moreover, field visits were conducted at dairy farms of varying scales across the Aydin region. These site visits (visual documents for these visits given in Annex) enabled the direct collection of localized data and insights from dairy farmers. The ground-truth information obtained through these engagements played a critical role in tailoring the Phase 2 analyses to the specific conditions of the region. This localized evidence base significantly enhanced the accuracy, credibility, and regional relevance of the climate risk assessments conducted. For the assessment of heat stress, the Temperature–Humidity Index (THI) was used as the primary indicator. THI is a widely applied metric that combines air temperature and relative humidity to quantify the level of heat stress experienced by dairy cattle. In addition, Heat Stress Degree-Days (HSDD) were calculated to capture the cumulative impact of heat stress over time. HSDD represents both the intensity and duration of exposure to THI values exceeding a defined physiological threshold, providing a robust measure of prolonged heat stress effects on dairy cattle. Although the geographic locations of individual dairy farms are available, analyses at the farm level could not be conducted due to confidentiality constraints and data protection regulations. Consequently, all hazard and risk assessments were carried out at the district level. Exposure and vulnerability indicators were aggregated using district-level attributes, such as the total number of cattle or the density of ventilation and cooling infrastructure. Based on these aggregated indicators, potential economic losses and related risk metrics were estimated and reported at the district scale.

2.3.1 Extreme Precipitation

Table 2-1 Data overview workflow #1

Hazard data	Vulnerability data	Exposure data	Risk output
Projected increase in heavy rainfall events derived from EURO-CORDEX (EUR-11, 12 km) multi-model ensemble projections under RCP4.5 and RCP8.5 scenarios.	*High sensitivity of dairy cattle and farm infrastructure to extreme precipitation, including susceptibility of animal housing, milking parlors, manure storage systems, and feed bunkers to flooding and waterlogging.*	*Number and spatial distribution of dairy farms located in flood-prone and agriculturally productive lowland areas of the province.*	*Increased flooding risk for dairy farms, characterized by more frequent and more intense inundation of farmyards, animal housing, and access roads*

2.3.1.1 Hazard assessment

For this analysis, the EURO-CORDEX (EUR-11) climate projections at a 12km spatial resolution were utilized (Copernicus Climate Change Service, 2019).. The workflow was implemented for the region under two emission scenarios (RCP4.5 and RCP8.5). The analysis was conducted for the western part of Turkey (Aegean region), while the time series were specifically generated for Aydin city extent. The 30-year frames of daily precipitation data were used for the analysis. The selected timeframes are 1976-2005 (baseline or historic simulations), 2041-2070 (mid-century) and 2071-2100 (end of the century).

The ensemble approach is essential in climate model analysis because no single model can perfectly represent the climate system. Different models use varying assumptions, parameterizations, and structures, which leads to uncertainty in their outputs. By combining multiple models, the ensemble approach reduces individual biases and errors, producing more reliable and robust projections. It also helps distinguish long-term climate signals from natural variability, while highlighting where models agree and where uncertainties remain. This makes projections more trustworthy and useful for risk assessments, adaptation planning, and clear communication of uncertainty to decision-makers. Therefore, for this analysis, we have adopted multi model ensemble approach. For ensemble approach, 44 GCM and RCM combinations were used and given in table.

Table 2-2 GMC and RCM combinations

GCM	RCMs
CanESM2	CLMcom-CCLM4-8-17, GERICS-REMO2015
CNRM-CM5	ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, GERICS-REMO2015, IPSL-WRF381P, KNMI-RACMO22E, MOHC-HadREM3-GA7-05
EC-EARTH	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, KNMI-RACMO22E, SMHI-RCA4
IPSL-CM5A-MR	DMI-HIRHAM5, GERICS-REMO2015, IPSL-WRF381P, KNMI-RACMO22E, SMHI-RCA4
MIROC5	CLMcom-CCLM4-8-17, GERICS-REMO2015, UHOH-WRF361H
HadGEM2-ES	CLMcom-CCLM4-8-17, ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, GERICS-REMO2015, IPSL-WRF381P, KNMI-RACMO22E, MOHC-HadREM3-GA7-05, SMHI-RCA4, UHOH-WRF361H

MPI-ESM-LR	CLMcom-CCLM4-8-17, ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, KNMI-RACMO22E, MOHC-HadREM3-GA7-05, SMHI-RCA4, GERICS-REMO2009, UHOH-WRF361H
NCC-NorESM1-M	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, GERICS-REMO2015, IPSL-WRF381P, KNMI-RACMO22E, MOHC-HadREM3-GA7-05, SMHI-RCA4

For each model, annual maximum precipitation values were derived and fitted to the General Extreme Value (GEV) distribution. Using these fits, expected precipitation levels were estimated for return periods of 2, 5, 10, 50, and 100 years. The analysis was carried out for both the historical period (1976–2005) and the future period (2041–2070) (not-shown) and (2071-2100) under the RCP4.5 (not shown) and RCP8.5 scenarios. Finally, the median values of the estimated return levels across all models were calculated.

Climate change projections indicate an increase in the frequency and intensity of extreme rainfall events in the region. This trend poses significant challenges for Aydin and a change in the 24-hr precipitation and return periods of events (i.e. 100-year) is significant for the region. The map of expected precipitation for 24hr duration for 100-year return period for future period (2071-2100) and relative change with respect to historical (1976-2005) period for RCP8.5 scenario are presented in Figure 2-15.

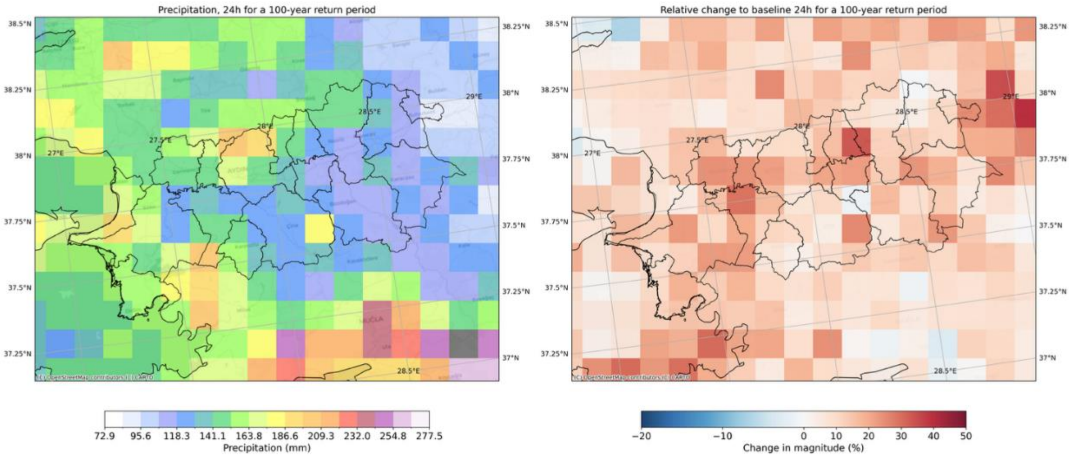

Figure 2-1 : The map of expected precipitation for 24hr duration for 100-year return period for historical (1976-2005) and future (2041-2070) periods in Aydin Region[2]

24-hour precipitation for a 100-year return period, reveals a significant east-west gradient in extreme rainfall intensity. The western coastal districts face substantial events in the 140-180 mm range, the central and eastern interior districts are projected to experience significantly more severe events, with precipitation totals exceeding 200mm and reaching upwards of 250mm in a single day. For dairy farmer, these indicate volumes of water that will almost certainly overwhelm standard on farm drainage infrastructure, leading to immediate and severe localized flooding of animal housing, milking parlors, and crucial feed storage bunkers. The relative change map shows the areas already receiving the highest absolute rainfall are also projected to see the greatest relative increase. Dairy operations in central and eastern Aydin will face 30% - 40% more intense than the historical worst-case scenarios. The results suggest a need for adaptation measures at the farm level, such as improved drainage, elevated or flood-resilient housing designs, protected feed storage, and revised risk management strategies, to safeguard dairy cattle welfare and sustain production under future climate conditions.

[2] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

2.3.1.2 Risk assessment

A threshold of 100 mm/24 hours has been established as the critical point for extreme precipitation in the region. Given the rising frequency of such events, coupled with their associated impacts and the number of warnings triggered annually, this workflow assesses the potential impact of climate change on historical critical thresholds. The analysis was expanded to cover the entire Aydin region. This broader scope provides insights into the overall impact of extreme precipitation across the area. The aim is to determine how the critical rainfall threshold of 100 mm/24 hours varies with different return periods under the effect of climate change. Figure 2-2 shows the current return periods for the 100 mm/24h rainfall threshold across Aydin, while the right map displays the expected return periods for the same threshold under the future climate scenario, RCP85 (2041-2070).

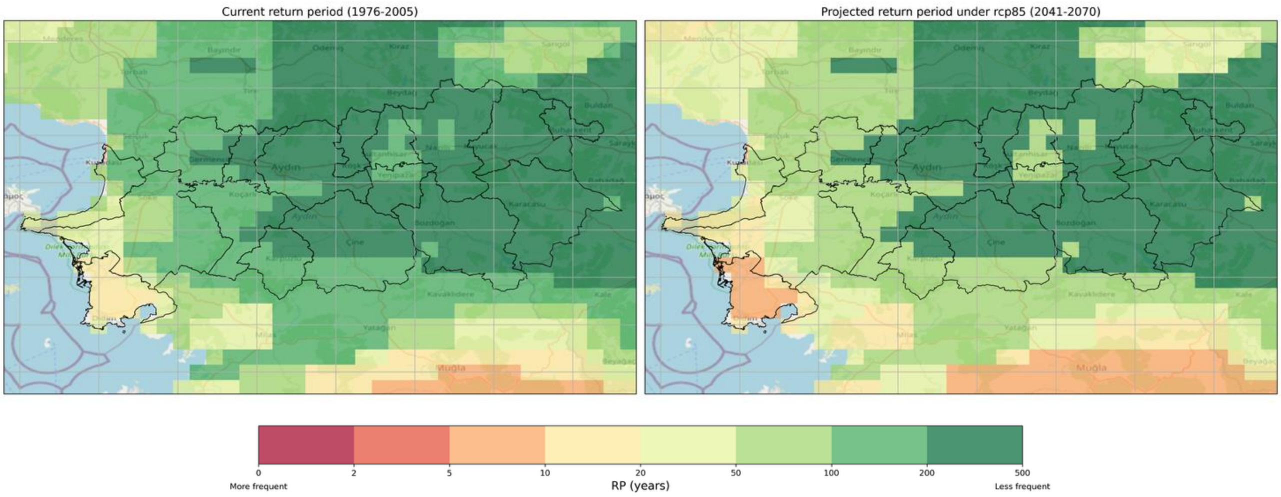

Figure 2-2 : Projected Changes in Return Period (Frequency) for 100mm/24h Events: 1976-2005 to 2041-Multi Model Ensemble | Scenario: RCP85[3]

Historically, 100 mm precipitation was relatively rare across much of the province. The projected patterns indicate a widespread shortening of the return period, particularly in lowland and agriculturally productive areas, meaning that 100 mm rainfall events are expected to occur much more frequently and can no longer be considered unusual. For dairy farms, this translates directly into increased exposure over the operational lifetime of buildings, animals, and equipment, with events that once occurred once or twice in a generation potentially happening multiple times within a farmer's career. The higher frequency raises the likelihood of repeated waterlogging of farmyards, flooding of access roads, and temporary isolation of holdings, disrupting milk collection, feed deliveries, and veterinary services even in the absence of major structural damage. Overall, the shortening of the return period for 100 mm precipitation shows a shift toward a more rainfall-intensive climate regime in Aydin. Figure 2-3 illustrates the percentage shift in precipitation within the Aydin region, highlighting the most significant changes in the frequency of 100 mm/24h events.

[3] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

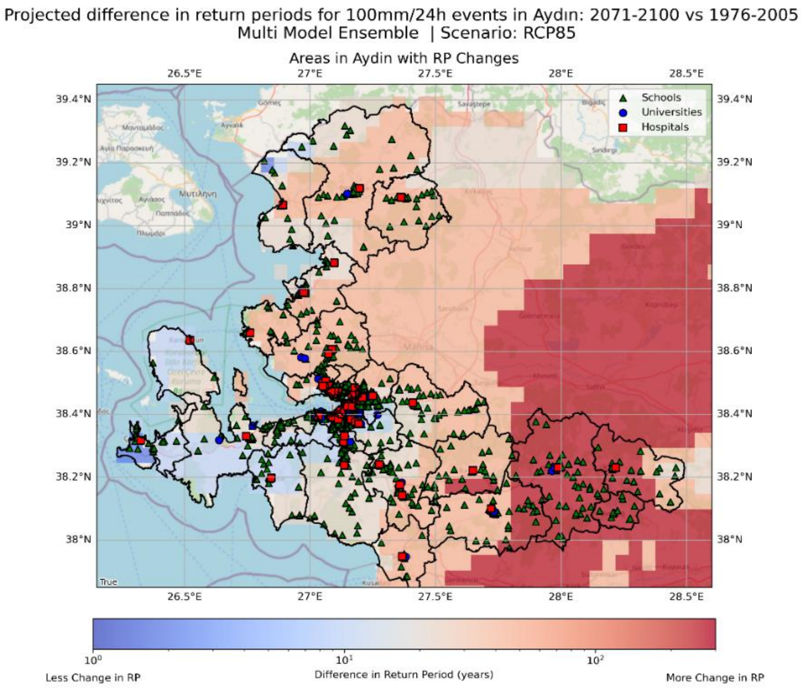

Figure 2-3 : Projected difference in return periods for 100mm/24h events in Aydin: 2041-2070 vs 1976-2005 Model Chain: Multi Model ensemble | RCP8.5[4]

The map clearly shows that many farms are situated within areas experiencing the strongest shifts in precipitation frequency, rather than on the margins of change. Large parts of central and eastern Aydin exhibit pronounced increases in the frequency of 100 mm events. The substantial share of the sector will be exposed to heavy rainfall events more often than in the historical climate.

Overall, the projected percentage shift in the frequency of 100 mm/24 h precipitation events indicates a clear escalation of climate risk for dairy farmers in Aydin. The alignment between strong increases in extreme rainfall frequency and farm locations shows that the urgency of integrating climate projections into farm management and investment decisions. For dairy producers, this means that future resilience will increasingly depend on anticipating more frequent heavy rainfall events and adapting infrastructure, drainage, and operational practices accordingly.

2.3.2 Heatwaves

Table 2-3 Data overview Heatwaves

Hazard data	Vulnerability data	Exposure data	Risk output
Climate model–derived air temperature and relative humidity from EURO-CORDEX (EUR-11) ensemble under historical (1976–2005) and RCP4.5 / RCP8.5 (2041–2070) scenarios; derived THI and HSDD indices	*Dairy cattle sensitivity to heat stress expressed through THI–impact relationships, including milk yield reduction (0.41 kg milk per cow per THI unit above threshold), fertility decline quantified via nonreturn rate (NRR) reduction (0.005 per THI unit above 66–70), and cooling requirements triggered by THI exceedance*	*Spatial distribution of dairy farms and herd locations at district level in Aydin; number of animals per district; duration of THI exceedance days affecting each production unit*	*District-level estimates of cumulative heat stress (HSDD), annual milk yield loss, fertility (NRR) decline, cooling energy demand and electricity cost, and total economic losses associated with climate-induced heat stress* .

[4] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

2.3.2.1 Hazard assessment

In this workflow, the effect of the increase in temperature and relative humidity on the dairy cattle's were assed in Aydin Region. The EURO-CORDEX (EUR-11) climate projections at a 12km spatial resolution were utilized under two emission scenarios (RCP4.5 and RCP8.5). The analysis was conducted with 30-year frames of daily temperature and relative humidity data. The selected timeframes are 1976-2005 (baseline or historic simulations) and 2041-2070 (mid-century). The ensemble approach is essential in climate model analysis because no single model can perfectly represent the climate system. Different models use varying assumptions, parameterizations, and structures, which leads to uncertainty in their outputs. By combining multiple models, the ensemble approach reduces individual biases and errors, producing more reliable and robust projections. It also helps distinguish long-term climate signals from natural variability, while highlighting where models agree and where uncertainties remain. This makes projections more trustworthy and useful for risk assessments, adaptation planning, and clear communication of uncertainty to decision-makers. Therefore, for this analysis, we have adopted multi model ensemble approach. For ensemble approach, 13 GCM and RCM combinations were used and given in table.

Table 2-4 GMC and RCM combinations

GCM	RCMs
CNRM-CERFACS-CNRM-CM5	IPSL-WRF381P, MOHC-HadREM3-GA7-05
ICHEC-EC-EARTH	KNMI-RACMO22E, SMHI-RCA4
MIROC-MIROC5	CLMcom-CCLM4-8-17
MOHC-HadGEM2-ES	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5
MPI-M-MPI-ESM-LR	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5
NCC-NorESM1-M	DMI-HIRHAM5, KNMI-RACMO22E, SMHI-RCA4

Heat stress is one of the most critical environmental challenges affecting dairy production, particularly in warm and humid regions such as Aydin. Rising temperatures due to climate change further intensify this problem, increasing both the frequency and duration of conditions that exceed the thermal comfort zone of dairy cattle. Heat stress is a condition in which the animal body has problems dissipating excess heat. Heat stress assessment methods were carried out using standardized temperature-humidity index (THI) to quantify the combined effect of temperature and humidity on animal welfare and productivity, as heat-stress indicator (Bouraoui et al., 2002).

$$THI = (1.8 \times T + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)$$

Where, T air temperature in °C and RH relative humidity in % (0–100).

For each model, THI index was derived using the temperature and relative humidity data then, the median values of the estimated THI values across all models were calculated in the Aydin Region.

Climate projections indicate further increases in temperature and humidity Consequently, the number of days exceeding critical THI thresholds is expected to rise significantly under both scenarios. The average of THI values in summer season for historical (1976-2005) period and future period (2041-2070) was calculated and presented in Figure 2-4.

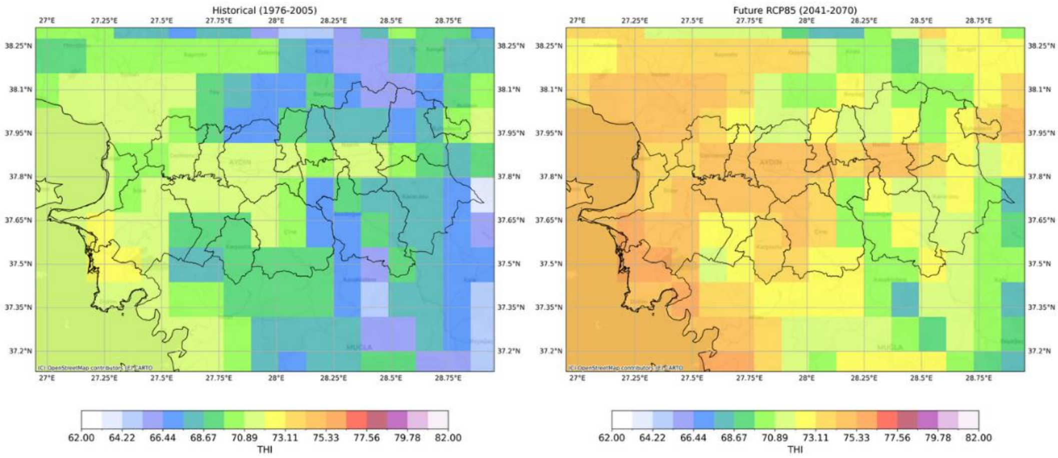

Figure 2-4 : Average of THI values in summer season for historical (1976-2005) period and future period (2041-2070)[5]

Using the daily THI data in Aydin, Heat Stress Degree-Days (HSDD) were calculated. HSDD shows how much and how long dairy cows are exposed to heat stress above a physiological threshold therefore it helps to quantify intensity and duration of the heat on the dairy cattle. HDSS will also be used to predict Milk yield loss, fertility decline, cooling demand and economic losses due to climate change. In Aydin, critical THI threshold was defined as 69 (Bouraoui et al., 2002; Cavallo et al., 2025; Collier et al., 2006). This threshold shows the THI value that heat load begins and negatively affects the cow's physiology, milk production, reproduction, or welfare.

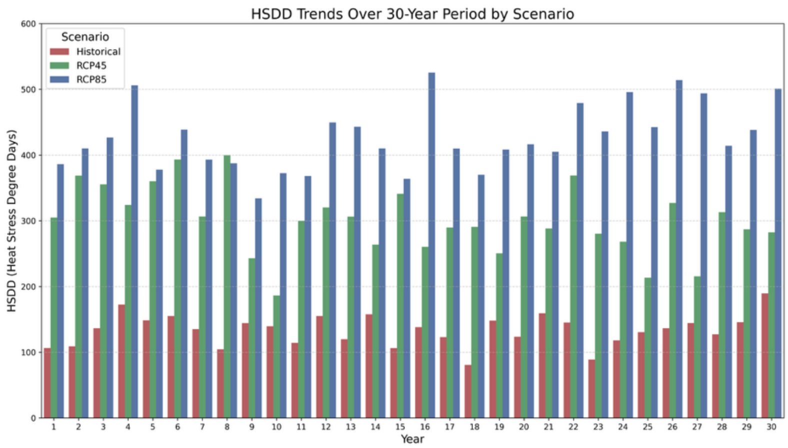

Figure 2-5 : Heat Stress Degree-Days (HSDD, average) in Aydin for each scenario (30-year period, historical (1976-2005), RCP45 (2041-2070), RCP85 (2041-2070)

The RCP4.5 and RCP8.5 scenarios exhibit a pronounced escalation in HSDD, with consistently high values throughout the period and frequent peaks indicative of severe and chronic heat stress. These levels suggest prolonged exposure to THI conditions well above critical thresholds, where recovery periods are insufficient and negative impacts on milk yield, fertility, and health are likely to compound over time.

[5] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

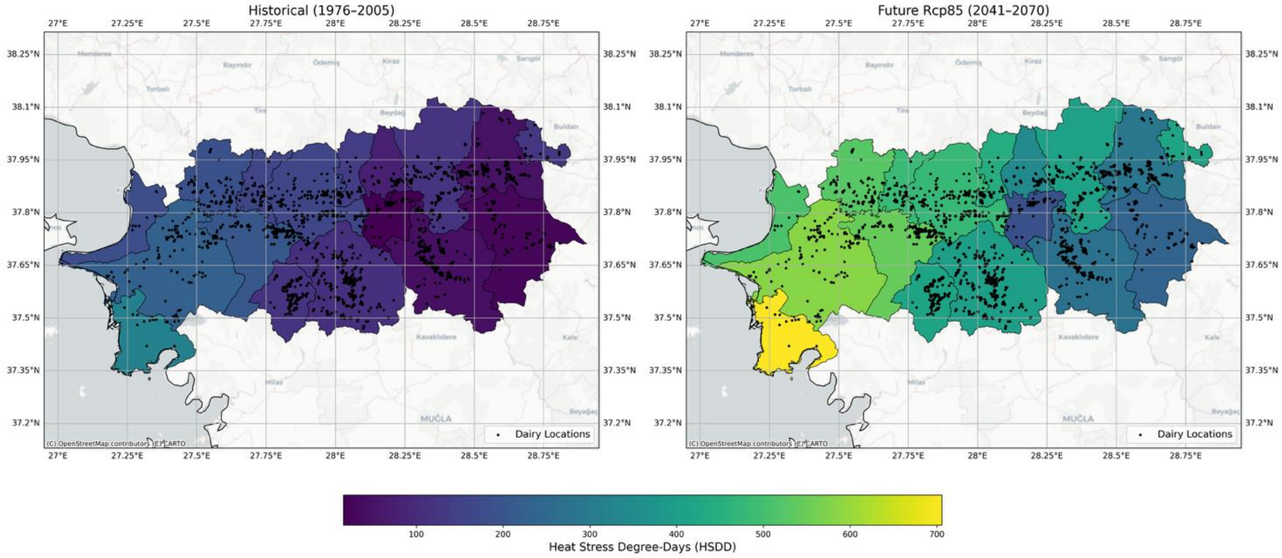

Figure 2-6 : Heat Stress Degree-Days (HSDD, average) for each district in Aydin for 30-year time period (left historical, right RCP8.5)[6]

The district-level mean HSDD maps reveal an increase in the cumulative heat stress across Aydin when comparing the historical period with the mid-century RCP8.5 scenario. Historically, HSDD shows a clear spatial gradient, with higher values in western and coastal districts such as Didim, Söke, and Kuşadası, and lower values in eastern and higher-elevation districts including Karacasu, Bozdoğan, Kuyucak, and Buharkent. Under RCP8.5, mean HSDD increases substantially in all districts. The largest increases occur in coastal and western districts while central and eastern districts also experience strong increases that push them well beyond historically observed ranges. The widespread rise in HSDD across districts, combined with the distribution of dairy farm locations, suggests that both traditionally high-risk and relatively favorable areas will face significant heat-stress pressure simultaneously.

2.3.2.2 Risk assessment

To evaluate the climate-related risks faced by the dairy sector in Aydin, we adopted a framework that integrates hazard, exposure, and vulnerability components into a single risk calculation. Heat-related hazards were quantified using district-level average Temperature-Humidity Index values and Heat Stress Degree-Days both of which are established indicators of thermal stress in dairy cattle. Humidity Index demonstrates that elevated thermal conditions significantly reduce milk production, feed efficiency, and animal comfort. Heat-Stress Degree Days indicator captures how often and by how much temperatures go above safe limits, reflecting the accumulated stress on animals or systems (Steinweg & Gutowski, 2015). Substantial productivity losses are observed once THI exceeds critical thresholds of approximately 68–71 (Rodriguez-Venegas et al., 2023). Therefore, the effects of increasing temperature and humidity on milk yield, fertility decline, and the associated economic losses were investigated in this study.

Previous findings by Hossain et al. (2023) and Bouraoui et al., 2002 shows that each unit increase in THI above a threshold of 69 is associated with an average reduction of approximately 0.41 kg of milk per cow per day. Exposure was defined as the total number of dairy cows in each district, representing the population at risk. Vulnerability, on the other hand, was determined by the presence or absence of ventilation fan systems, specifically ventilation fans, on dairy farms. In this context,

[6] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

farms without cooling systems were considered fully vulnerable to heat-induced production losses. To assess the mitigating effect of mechanical ventilation on heat-induced milk losses, an estimation of fan presence across farms was carried out based on field insights provided by CBAA personnel. Farms were categorized by size as follows: small (0–20 head), medium (20–50 head), and large (>50 head). Based on expert input, it was assumed that 20% of small farms, 30% of medium farms, and 100% of large farms are equipped with mechanical ventilation systems. Using this assumption, district-level fan counts were derived by applying these proportions to the total number of farms per size category. These estimated fan counts were then integrated into the risk model to represent each district's resilience capacity—i.e., the proportion of livestock potentially protected from heat stress. This allowed the heatwave risk assessment to not only quantify projected milk yield losses under increasing THI conditions but also adjust for the expected mitigating effect of existing cooling infrastructure, providing a more realistic and context-sensitive analysis of vulnerability.

The risk for each district was calculated using the following expression:

$$\text{Risk}_{\text{district}} = \text{HSDD}_{\text{year}} \times \text{Number of Cows}_{\text{district}} \times \text{Milk Loss}_{\text{cow/day}} \times \text{Fan Availability Score}$$

This approach combines the climatic severity of heat stress, the scale of exposed livestock, the expected per-cow milk yield loss due to increased THI, and the mitigating effect of cooling infrastructure.

Using this relation, the HSDD metric was used to estimate annual cumulative milk yield losses per cow for each district. Figure 2-7 presents the mean annual cumulative milk loss per herd, averaged over the 30-year analysis period.

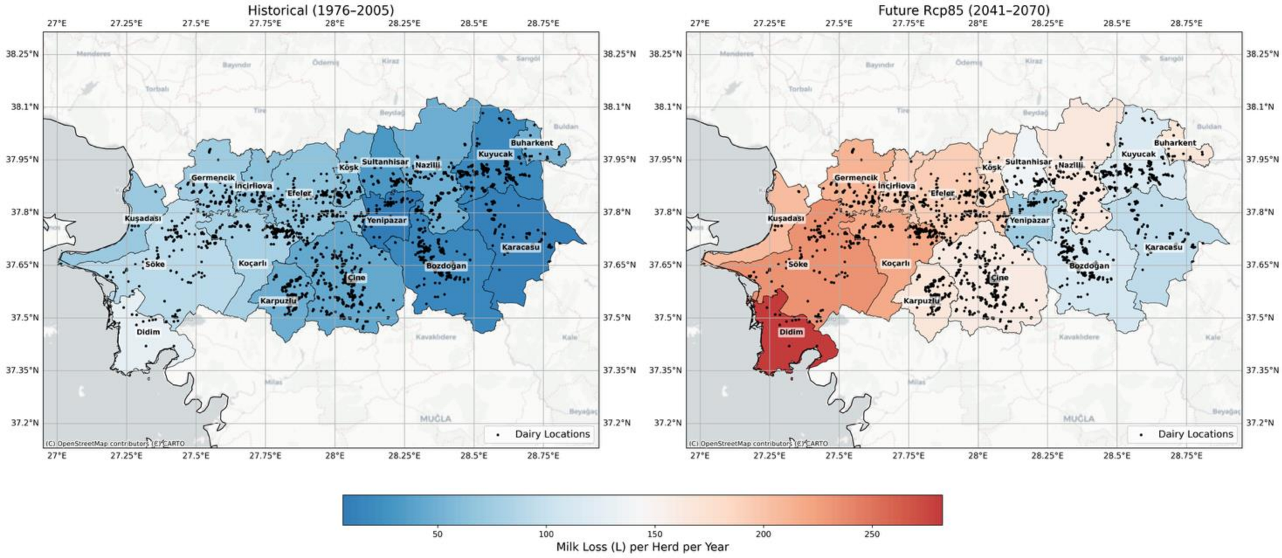

Figure 2-7 : Annual cumulative milk loss per herd for each district in Aydin for 30-year time period (left historical, right RCP8.5)[7]

Didim emerges as the most affected district, with losses locally exceeding about 250 L yr⁻¹, followed by Söke and Kuşadası, where values commonly range between 180 and 220 L yr⁻¹. Central districts such as Efeler, Germencik, İncirliova, Koçarlı, and Yenipazar show marked increases to roughly 150–200 L yr⁻¹, indicating a transition from moderate to high heat-stress impacts. Eastern districts, while still comparatively lower, experience increases to around 120–160 L yr⁻¹, representing a doubling or more relative to historical conditions. The comparison between historical and RCP8.5 projections reveals that climate change will both intensify and broaden the geographic reach of heat-induced milk loss across the region. Most districts are expected to see a two to three-fold surge in average annual cumulative milk loss per herd.

[7] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

To assess the vulnerability of dairy farms in each district, milk loss was calculated based on the presence or absence of mechanical cooling systems. While heat stress typically reduces production, the widespread use of ventilation fans serves as a primary mitigation strategy by increasing air velocity and promoting heat dissipation. In this analysis, it is assumed that cows with access to fans are maintained at optimal thermal conditions and experience no heat-induced milk loss. Consequently, production declines are attributed only to the portion of the herd lacking ventilation. By determining the ratio of cooled to non-cooled animals per district and applying the Turkish National Dairy Council's (TNDC) price of 0.39 € per liter, the average annual economic loss was quantified for each district. Figure 2-8shows total number of ventilation fans per district and Figure 2-9 shows annual cumulative economic loss due to the milk production loss.

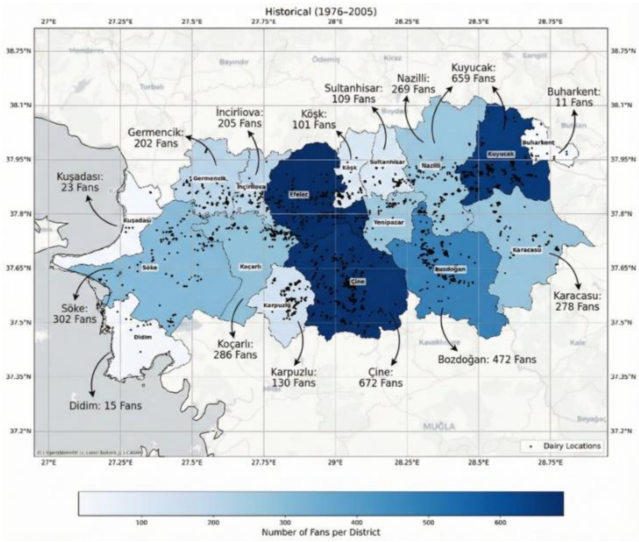

Figure 2-8 : Total number of ventilations per district in Aydin[8]

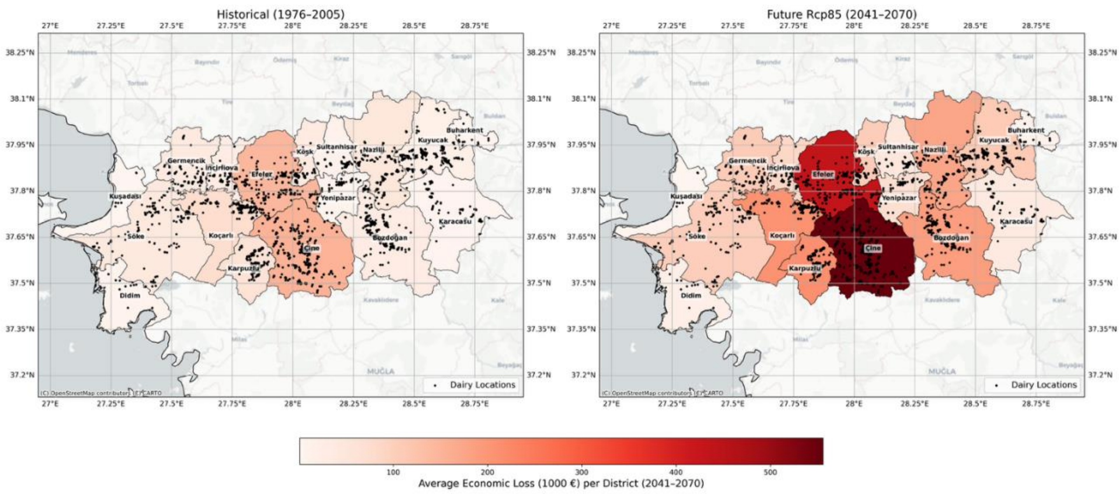

Figure 2-9 : Annual cumulative economic loss due to milk loss for each district in Aydin for 30-year time frame (left historical, right RCP8.5)[9]

In the RCP8.5 scenario, several districts transition into high-impact zones, with mean annual losses commonly exceeding 200–300 thousand € per district. The most severe impacts are observed in central districts, particularly Çine and Efeler, where losses locally exceed 400–500 thousand € per year, driven by the combination of very high cumulative heat stress and dense dairy production.

[8,10] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

Western districts such as Söke and Didim also experience strong increases, reaching approximately 250–350 thousand € per year, while northern and eastern districts, although still relatively lower, show substantial increases compared to the historical period.

In addition to productivity declines, this analysis considers the financial burden of operating ventilation fans. To maintain optimal thermal conditions, it is assumed that fans run continuously for 24 hours on any day where the Temperature-Humidity Index (THI) exceeds the critical threshold. The total operational cost was determined by calculating the number of days exceeding this threshold and applying a power consumption rate of 1 kWh per fan. Using the Energy Market Regulatory Authority (EPDK) rate of 0.12 € per kWh, the average annual expenditure for electricity was projected for each district over a 30-year period.

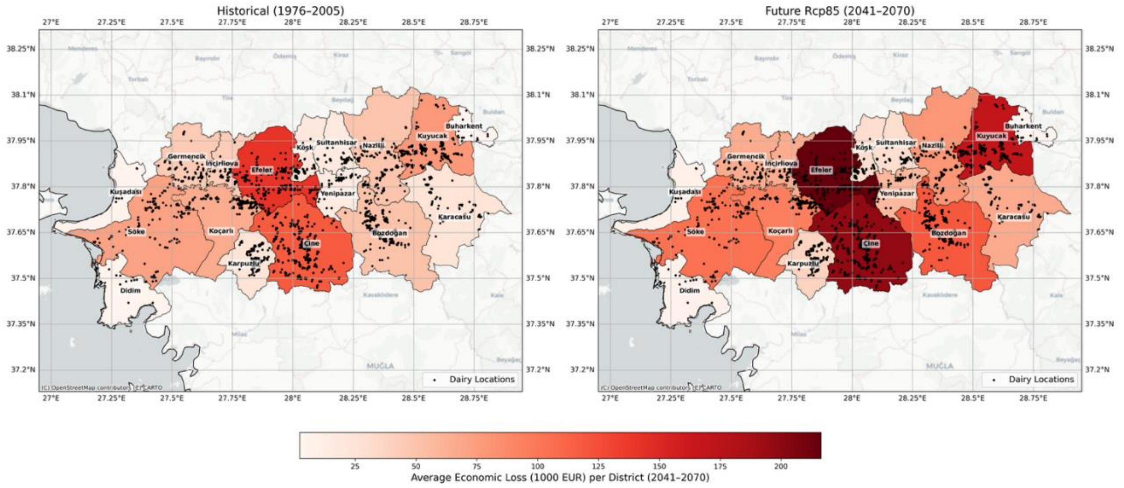

Figure 2-10 : Annual cumulative economic loss due to fan usage for each district in Aydin for 30-year time frame (left historical, right RCP8.5)[10]

In historical conditions, fan-related electricity costs are generally moderate, with most districts exhibiting average annual expenditures below approximately 50–100 thousand € per district. Under the RCP8.5 scenario, electricity costs rise markedly across all districts. Several districts transition into high-cost categories, with mean annual expenditures commonly exceeding 100–150 thousand € per district. The most pronounced increases are observed in central districts, particularly Efeler and Çine, where projected costs locally exceed 200 thousand € per year. Western districts such as Söke and Didim also show substantial increases, indicating a growing energy burden associated with prolonged heat-stress conditions. Eastern districts, including Karacasu, Bozdoğan, Kuyucak, and Buharkent, remain relatively lower but still experience clear upward shifts compared to historical levels. Overall, the comparison of historical and future maps demonstrates that climate change not only amplifies direct productivity losses but also significantly increases the recurring operational costs required to maintain acceptable thermal conditions in dairy facilities.

In addition to reductions in milk yield and increased cooling costs, heat stress has a well-documented negative impact on reproductive performance in dairy cattle. To capture the effects of thermal stress on conception rate, the Temperature-Humidity Index (THI) was used as the primary hazard metric. District-level average THI values were computed, and the number of Heat Stress Degree-Days (HSDD) above a defined threshold was used to measure cumulative thermal load. Based on literature findings (e.g., Ravagnolo et al., 2000), each unit increase in THI beyond critical thresholds (typically 66–70) is associated with a reduction in the Non-Return Rate (NRR) of

[10] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

approximately 0.005 to 0.007 units. The NRR is widely used as an indicator of reproductive performance, with lower values signaling decreased fertility.

The total impact on fertility was estimated by combining climate stress with exposure and vulnerability factors. Exposure was defined by the number of dairy cows in each district, while vulnerability was assessed based on the presence of mechanical ventilation systems (fans) on farms. It was assumed that farms equipped with effective cooling systems maintained more favorable thermal conditions and therefore experienced less reproductive impairment. In the analysis of the relationship between heat stress and conception rate, vulnerability was assessed using the same approach described at the beginning of Section 2.3.2 for ventilation fans. Accordingly, the mitigating effect of mechanical ventilation was incorporated into the fertility assessment by adjusting exposure based on the estimated proportion of livestock housed in farms equipped with ventilation systems. This ensured methodological consistency across productivity and fertility analyses and allowed the heat-induced decline in conception rates to be applied only to the fraction of animals considered unprotected from thermal stress.

The composite risk related to conception efficiency was calculated using the following formulation:

$$\text{Conception\_Rate}_{\text{district}} = \text{HSDD}_{\text{year}} \times \text{Number of Cows}_{\text{district}} \times \Delta \text{NRR}_{\text{unit THI}} \times \text{Fan Availability Score}$$

Conception rate is particularly sensitive to elevated Temperature–Humidity Index (THI) levels, as heat stress disrupts hormonal balance, suppresses estrus expression, impairs oocyte quality, and increases early embryonic loss. Ravagnolo and Misztal (2000) reported that the nonreturn rate began to decline at THI values ranging from 66 to 70, depending on the geographical region analyzed. Beyond this threshold, the nonreturn rate decreased by approximately 0.005 to 0.007 per unit increase in THI. The nonreturn rate (NRR) represents the proportion of inseminated cows that do not return to estrus within a defined period and is widely used as an indirect indicator of fertility, with values above 0.65 indicating good reproductive performance, values between 0.55 and 0.65 indicating moderate performance, and values below 0.55 suggesting poor fertility and a likely influence of heat stress. To quantify the impact of heat stress, a decline of 0.005 units in the non-return rate was applied for every unit increase in the Temperature-Humidity Index (THI). While these calculations were performed on a daily basis, the influence of heat stress is most pronounced during the summer. Consequently, the following figure illustrates the average non-return rate decrease specifically for July, comparing historical data against future projections.

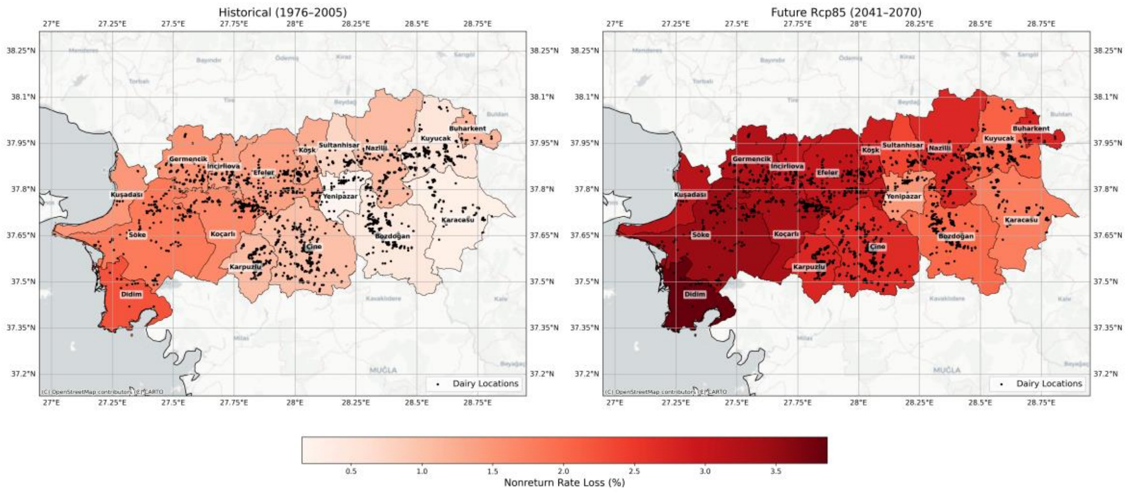

Figure 2-11 : Average non-return rate decreases in July for each district in Aydin for 30-year time frame (left historical, right RCP8.5)[11]

[11] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

Under historical conditions, NRR losses are generally limited, with most districts exhibiting values below approximately 1–1.5%. Lower fertility impacts are particularly evident in eastern districts such as Karacasu, Bozdoğan, Kuyucak, and Buharkent. Under the RCP8.5 scenario, mean NRR losses commonly exceed 2–3% over much of the region, with the highest impacts observed in coastal and central districts. Didim, Söke, Koçarlı, Germencik, İncirliova, Efeler, and Çine emerge as clear hotspots, where projected NRR losses locally approach or exceed approximately 3.5–4%. These levels imply a systematic degradation of reproductive performance, with many herds likely transitioning from moderate fertility conditions toward values associated with poor reproductive performance and strong heat-stress influence.

2.3.3 Agricultural Drought

Table 2-5 Data overview Agricultural Drought

Hazard data	Vulnerability data	Exposure data	Risk output
Climate-driven precipitation deficit during the growing season derived from EURO-CORDEX (EUR-11) multi-model ensemble projections (13 GCM–RCM combinations) under RCP4.5 and RCP8.5 scenarios for the 2046–2050 period; associated changes in temperature, humidity, radiation, and wind affecting evapotranspiration	*Crop-specific sensitivity to water stress quantified through FAO I&D 33 yield–evapotranspiration response functions, incorporating crop parameters, thermal climate zones, soil available water capacity, and evaporative demand; vulnerability expressed as percentage yield loss under rainfed conditions*	*Spatial distribution of cultivated areas for 11 forage and food crops at district level in Aydin; historical crop yields (2024) and production volumes obtained from the Provincial Directorate of Agriculture; crop-specific producer prices from 2024 FAOSTAT*	*District-scale estimates of yield loss (%) and production loss (tons) for forage and cereal crops; crop-specific and district-level revenue losses expressed as lost opportunity cost (thousand EUR/USD) under non-irrigated conditions, identifying hotspots of economic risk due to precipitation deficits*

2.3.3.1 Hazard assessment

Climate change poses a significant risk to forage crop production, which forms the foundation of dairy systems and largely determines feed availability, quality, and production costs. Forage crops are highly sensitive to changes in temperature, precipitation patterns, and the frequency of extreme events such as heatwaves and droughts. Therefore, this workflow evaluates the impact of water deficit on crop yields in the Aydin region, focusing on 11 crops that are critical for both forage and food production. These include triticale; vetches; clover (forage and silage); grasses (forage and silage); oats; sorghum for forage and silage; maize for forage and silage; barley; green peas; rye grass (forage and silage); and wheat. The EURO-CORDEX (EUR-11) climate projections at a 12 km spatial resolution were utilized under two emission scenarios (RCP4.5 and RCP8.5). The analysis was conducted with 5-year frame (2046-2050) of daily mean precipitation flux, maximum and minimum temperature, 2 m relative humidity, surface downward solar radiation and 10 m wind speed as well as data on soil available water capacity (Gupta et.al., 2019), elevation (Danielson et.al., 2011) and thermal climate zone (FAO , *2022*). Additionally, for this analysis, multi-model ensemble approach was adopted. For ensemble approach, 13 GCM and RCM combinations were used and given in table.

Table 2-6 GMC and RCM combinations

GCM	RCMs
CNRM-CERFACS-CNRM-CM5	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, GERICS-REMO2015, IPSL-WRF381P, KNMI-RACMO22E
ICHEC-EC-EARTH	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, KNMI-RACMO22E, SMHI-RCA4

MOHC-HadGEM2-ES	IPSL-WRF381P
MPI-M-MPI-ESM-LR	CLMcom-ETH-COSMO-crCLIM-v1-1, DMI-HIRHAM5, KNMI-RACMO22E, SMHI-RCA4

In hazard assessment, the impact of precipitation deficits on yield loss for 11 key crops in the region is analyzed. 11 forage crops cultivated in the region playing a crucial role in sustaining dairy farming. The historical yield (2024) for forage crops using in dairy farming were obtained from Provincial Directorate of Agriculture of Turkey. The agricultural hazard assessment follows a sequential four-step workflow to quantify the impact of water scarcity on crop productivity. The process begins by calculating the reference evapotranspiration (ET_0) using the Penman-Monteith equation (Allen et al., 1998). Once this baseline is established, it is combined with crop-specific parameters and thermal climate zone data to determine the crop standard evapotranspiration (ET_c), representing the maximum potential water demand for a specific plant. In the third stage, the model integrates local precipitation data to estimate the actual crop evapotranspiration (ET_a), which reflects the real amount of water available to the plant relative to its potential. Finally, the ratio between this actual evapotranspiration and the maximum potential is processed through FAO I&D 33 equations to calculate a final percentage of crop yield loss under rainfed conditions (FAO, 2012). Crop-specific parameters were defined for each crop. Crop coefficients, lengths of the growing period, and sowing and harvest dates were obtained from Chapagain and Hoekstra (2004) and Allen et al. (1998). Rooting depth and soil water depletion factors were taken from Allen et al. (1998), while crop water–yield response factors were derived from *FAO* (2012). This methodology is currently applied to 15 parameterized crops using inter-annually averaged climate data to simulate the impacts of precipitation scarcity during a typical growing season. Following the determination of individual yield loss values, the district-scale impact is established by calculating the mean loss across each specific district. To ensure robust results across different climate scenarios, this procedure is applied to every ensemble member within the climate models. The final yield loss figure is then derived by taking the median of these collective outputs, providing a representative measure that accounts for model variability. As an example, Figure 2-12shows the historical yield (kg/ha) and average yield loss (%) for RCP8.5 scenario in 2046-2050 years.

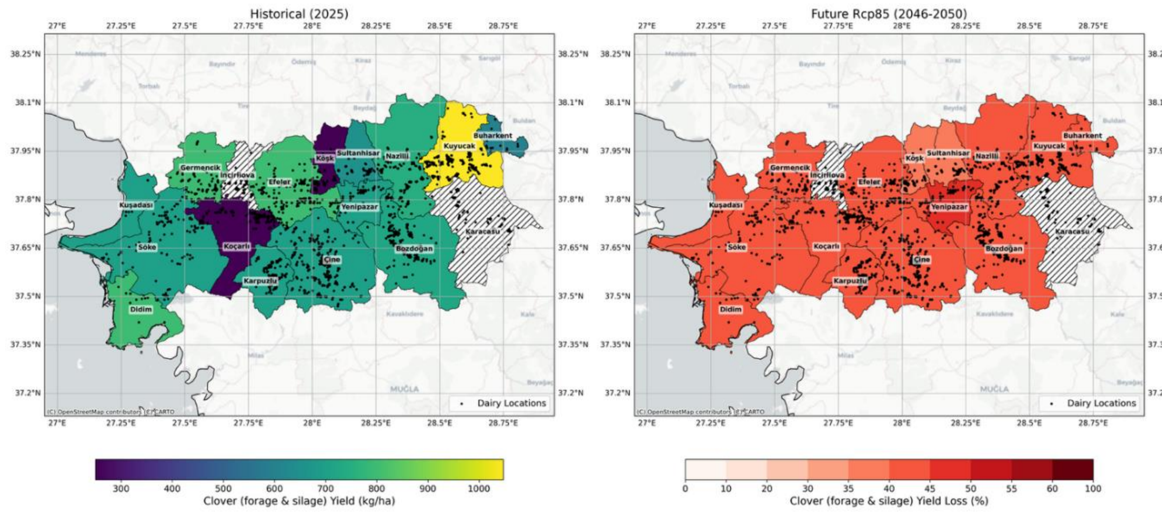

Figure 2-12 Historical Clover yield (left) and yield loss (right) from precipitation deficit in the region between 2046-2050 for RCP8.5 scenario[12]

Higher historical yields are generally observed in districts with more favorable soil and climatic characteristics. The projected yield loss map shows decrease in nearly all districts, indicating that

[12, 15] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

precipitation deficits during the growing season become a dominant constraint on forage production. The magnitude of losses varies spatially, with several central and western districts experiencing particularly high reductions, in some cases exceeding 40–60%. These areas coincide with regions where evaporative demand increases strongly due to higher temperatures, while precipitation is insufficient to meet crop water requirements, resulting in a pronounced gap between potential and actual evapotranspiration. Additionally, using the cultivation area for each crop, total production and production loss were also investigated.

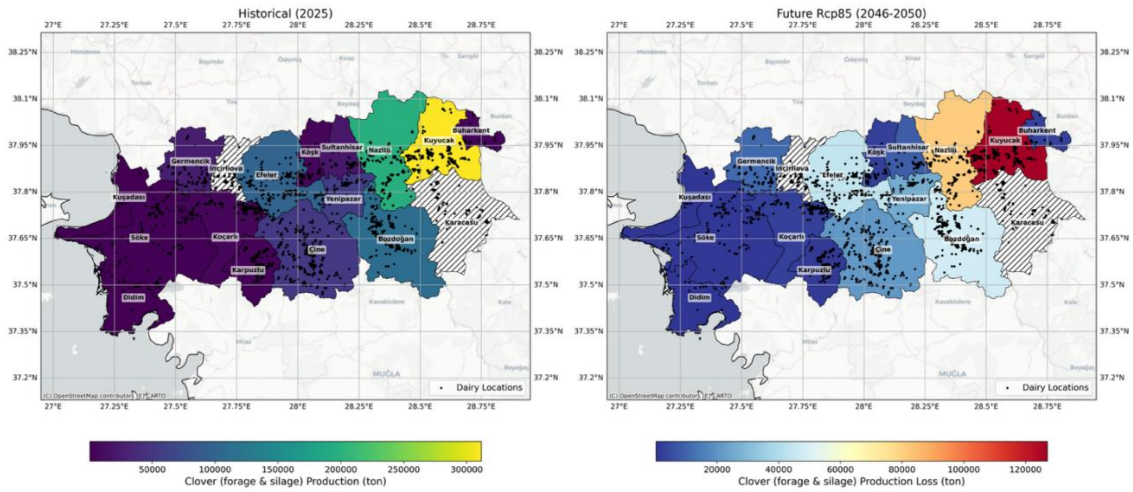

Figure 2-13 Historical Clover production, ton (left) and production loss, ton (right) from precipitation deficit in the region between 2046-2050 for RCP8.5 scenario[13]

Similarly, remaining crops show substantial decrease in yield and given as supplementary.

2.3.3.2 Risk assessment

The risk analysis investigates potential revenue losses in the Aydin region resulting from irrigation deficits, tailored to specific crops, emission scenarios, and future periods. Losses are expressed as the 'lost opportunity cost' (in thousands of euros) incurred if crops are grown without irrigation. Using 2024 FAOSTAT producer prices as a baseline (FAOSTAT, 2024), the analysis assumes a total shift to non-irrigated conditions. These maps enable demonstrators to identify the most impacted areas and determine which crops are most vulnerable to the absence of irrigation

Figure 2-14 presents maize and wheat revenue loss due to precipitation deficit in the region between 2046-2050 under the RCP8.5 scenario.

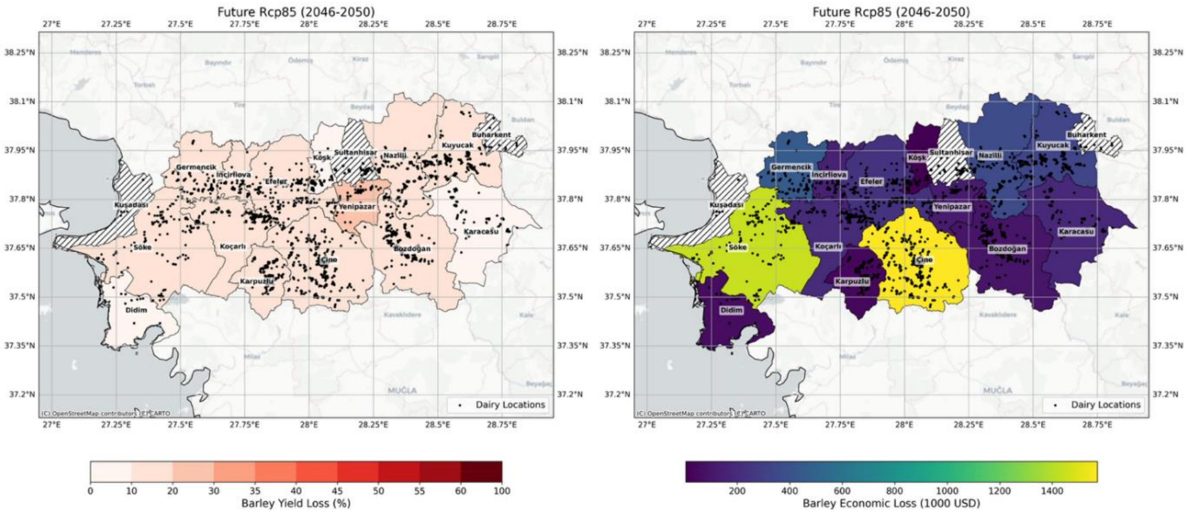

Figure 2-14 : Barley yield loss (%) (left) and revenue loss (right) due to precipitation deficit in the region between 2046-2050 under the RCP8.5 scenario.[14]

The maps indicate that under the RCP8.5 scenario (2046–2050), barley yield losses due to precipitation deficits generally range from approximately 5–20% across most of Aydin. Yield losses remain relatively modest compared to more water-demanding crops, with many districts such as Germencik, İncirliova, Efeler, Nazilli, Kuyucak, and Buharkent exhibiting losses predominantly below about 15%. Slightly higher losses, locally approaching 20–25%, are observed in parts of Söke, Koçarlı, Çine, and Yenipazar, where increased evaporative demand and lower effective precipitation coincide. In contrast, the associated economic losses show much stronger spatial differentiation. Söke and Çine experience the highest economic impacts, with mean annual revenue losses reaching approximately 1.2–1.5 million USD per district under non-irrigated conditions. Koçarlı and Efeler also show substantial losses, typically in the range of 800–1,200 thousand USD, reflecting their large production volumes. Germencik and İncirliova exhibit moderate economic losses on the order of 400–700 thousand USD, while eastern districts such as Karacasu, Kuyucak, and Buharkent generally remain below 300–400 thousand USD, despite experiencing comparable percentage yield reductions. Overall, the numerical contrast between yield loss and economic loss confirms that economic exposure dominates district-level risk patterns.

2.3.4 River Flooding

Table 2-7 Data overview Heatwaves

Hazard data	Vulnerability data	Exposure data	Risk output
• Flood water depth maps for return periods 2, 5, 10, 50, 100, 500 years • Future hazard adjusted using relative change factors from the heavy rainfall workflow (RCP8.5, 2071–2100) • High-resolution topography from GEDTM30 (30 m) • Manning's roughness derived from ESA WorldCover (10 m)	*•Global flood depth–damage functions (vulnerability curves) developed by Joint Research Centre • Non-linear response: incremental depth increases lead to disproportionate damage escalation • Applied consistently for baseline and future scenarios*	*• Land use / land cover data from LUISA Base Map • Spatial distribution of dairy farm locations (points) within the Büyük Menderes floodplain*	*• Spatially explicit flood damage maps (€) for the 1-in-100-year event (baseline and RCP8.5) • Relative change (%) in flood damages between historical and future periods*

[14] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

2.3.4.1 Hazard assessment

In the river flooding hazard workflow, the flood risk in the Büyük Menderes Basin was evaluated. A rain-on-grid hydrodynamic modelling approach was applied to generate water depth maps corresponding to different return periods (2, 5, 10, 50, 100, and 500 years). For this purpose, high-resolution topographic data (30 m) covering the entire basin were obtained from Global Ensemble Digital Terrain Model 30m (GEDTM30) (Ho & Hengl, 2025). In addition, land cover information was derived from ESA WorldCover (Zanaga et al., 2022), a global land cover product for 2021, which provides 11 land cover classes at a 10 m resolution. These classes were used to assign Manning's roughness values across the basin. The topography and land cover data used for the modelling are presented below.

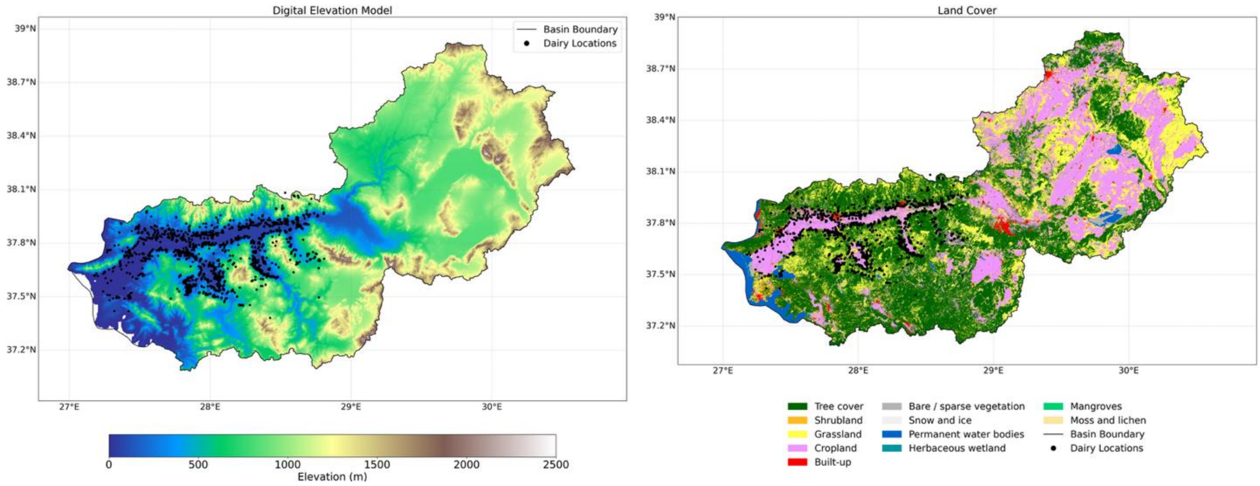

Figure 2-15 : The topographic (left) and land cover map (right) in Büyük Menderes basin[15]

Historical precipitation maps for different return periods were generated using spatial interpolation (spline) of extreme precipitation values observed in the region. In this process, data from 40 stations with at least 40 years of records, located within and around the Büyük Menderes Basin, were utilized. To estimate future changes, relative differences with respect to the historical period were derived from the heavy rainfall workflow presented in this report. These relative changes were then applied to the historical precipitation maps to obtain projections of future extreme precipitation for return periods of 2, 5, 10, 50, 100, and 500 years. The future period considered was 2071–2100 under the RCP8.5 scenario. Figure 2-16illustrates the comparison of historical and future (2071–2100, RCP8.5) precipitation for the 100-year return period in the Aydin Region.

[15] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

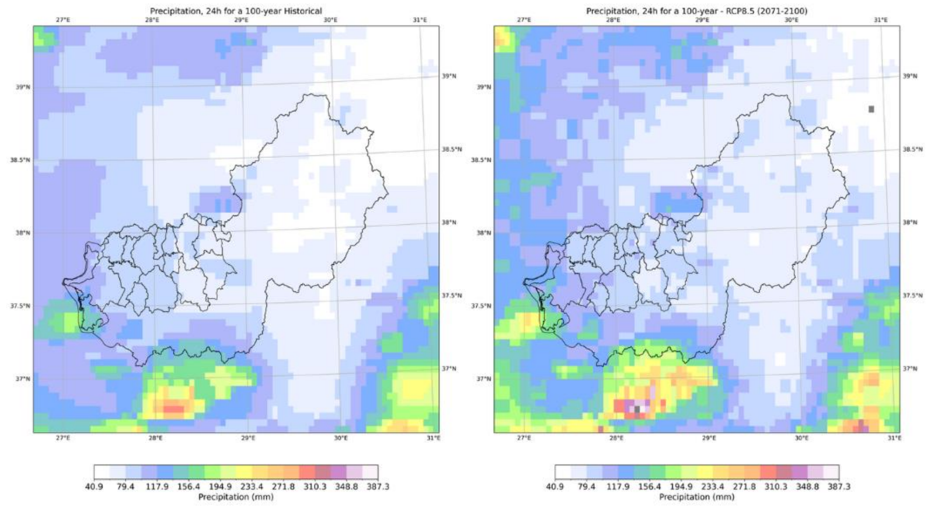

Figure 2-16 : The precipitation maps for the 100-year return period in the Aydin Region (left historical, right RCP8.5 -2071-2100)[16]

Both historical and future (2071–2100) periods were modelled using the GPU-accelerated LISFLOOD-FP two-dimensional hydrodynamic model to simulate inundation from extreme events in the Aydin Region (Sharifian et al., 2023). Simulations were carried out for six flood return periods, ranging from 1-in-2 years to 1-in-500 years. This approach made it possible to assess not only the historical flood risk but also projected changes under future conditions. The resulting maps cover large river basins such as the Büyük Menderes; however, they do not account for flood protection measures, which may result in overestimated flooding in certain areas. Similarly, the underlying river model excludes water management practices. Consequently, the maps should be interpreted as representations of the overall flood hazard in the region. The figure shows 100-year flooding for future period (2071-2100) and its relative change (%) with respect to historical period.

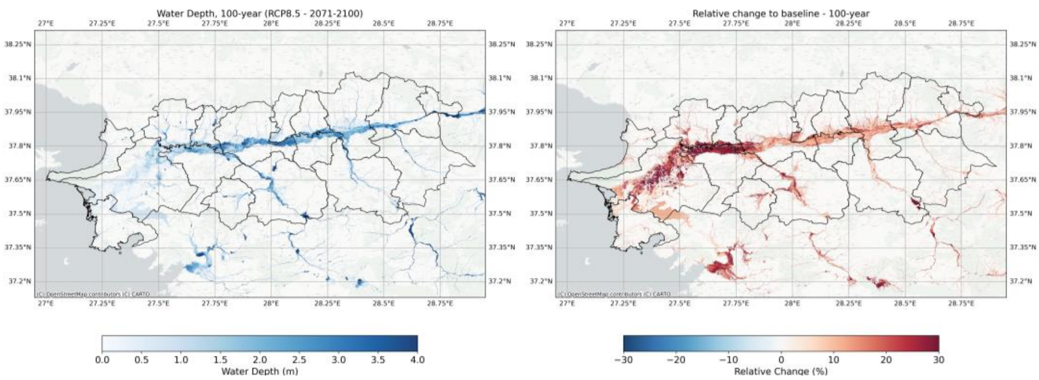

Figure 2-17 : The 100-year flooding for future period (2071-2100) and its relative change (%) with respect to historical period (right)[17]

Under the RCP8.5 scenario (2071–2100), the maps reveal a significant intensification of the 100-year flood hazard across the Büyük Menderes Basin. Central and downstream floodplains face depth increases of 20–30%, threatening to inundate grazing lands, forage crops, and farm infrastructure. This heightened exposure creates a compound risk scenario when combined with projected heat stress and rising costs. Consequently, future farm management must prioritize flood resilience, particularly regarding the sitting of facilities and the protection of feed and manure storage against deep inundation.

[16, 20] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

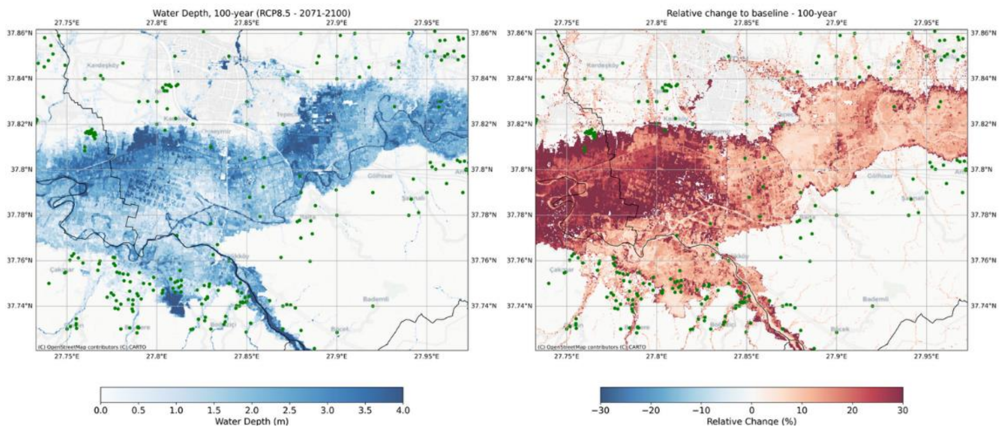

Figure 2-18 : The 100-year flooding for future period (2071-2100) and its relative change (%) with respect to historical period (right)[18]

The zoomed-in maps highlight a significant spatial overlap between dairy infrastructure and intensifying flood hazards. Under the RCP8.5 scenario, farms in the Büyük Menderes floodplain face projected inundation depths of 1–3 meters, representing a relative increase of 20–30% over historical conditions. This intensification suggests that future floods will be deeper and more destructive at sites previously considered safe. Consequently, the sector faces critical vulnerabilities regarding livestock safety and operational continuity, underscoring the urgent need for integrated risk management and flood-resilient farm planning.

2.3.4.2 Risk assessment

Risk assessment was assessed to visualize risks to build infrastructure presented by river flooding in the region. Water depth maps in hazard assessment and land use/land cover map developed and produced by the JRC (LUISA Base Map 2018, (Pigaiani & Batista e Silva, 2023) were used for various types of urban areas, natural land, agricultural fields, infrastructure and waterbodies.

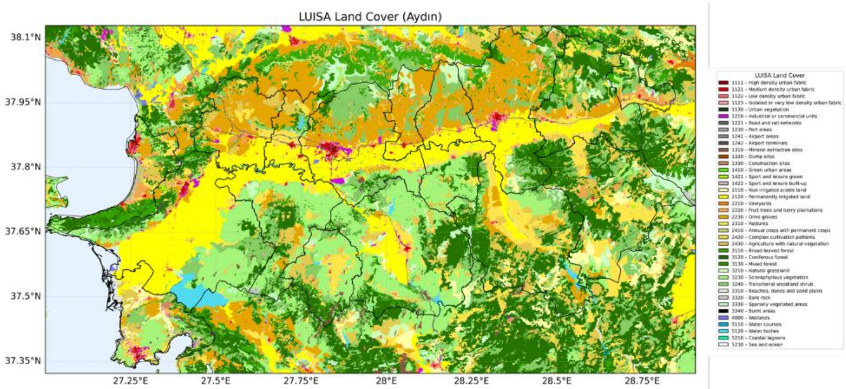

Figure 2-19 LUISA Land Cover Map for Aydin Region.[19]

Additionally, for risk analysis global flood depth-damage functions (vulnerability curves) were used by JRC (Huizinga et al., 2017). The figure shows the maps of flood and associated damages for extreme river water level scenarios in current climate 1 in 100-year extreme event for Aydin Region and its relative change in future based on the RCP8.5 scenario.

[18] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

[19,23] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

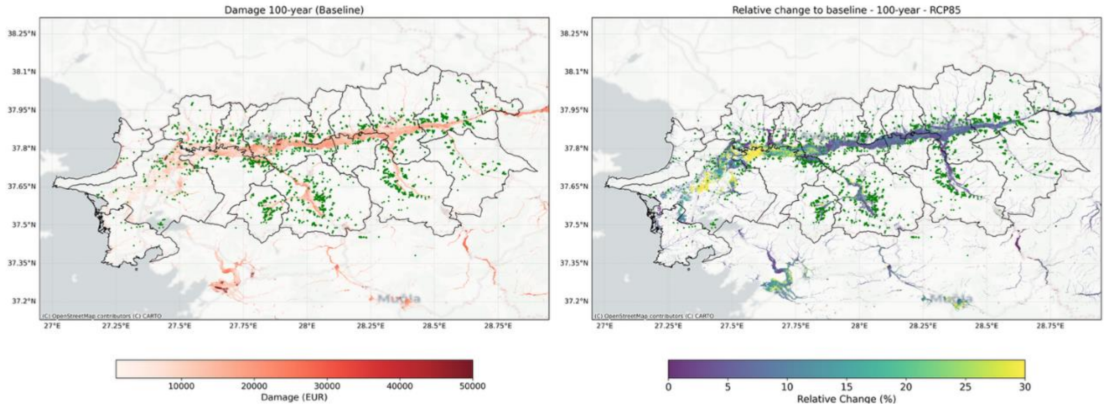

Figure 2-20 The maps of flood and associated damages for extreme river water level scenarios in current climate (left) and RCP8.5 scenario (2071-2100) for 1 in 100-year extreme event for Aydin Region.[20]

Baseline 100-year flood damages in the Büyük Menderes floodplain are concentrated in the €10,000–€30,000 range, with industrial and urban hotspots reaching €50,000. Under the RCP8.5 scenario, damages are projected to increase across the network, with most river segments experiencing a 5–25% rise. The most significant increases (25–30%) occur in high-baseline areas, reflecting the non-linear impact of the JRC depth-damage functions, where incremental depth increases result in disproportionately higher economic losses.

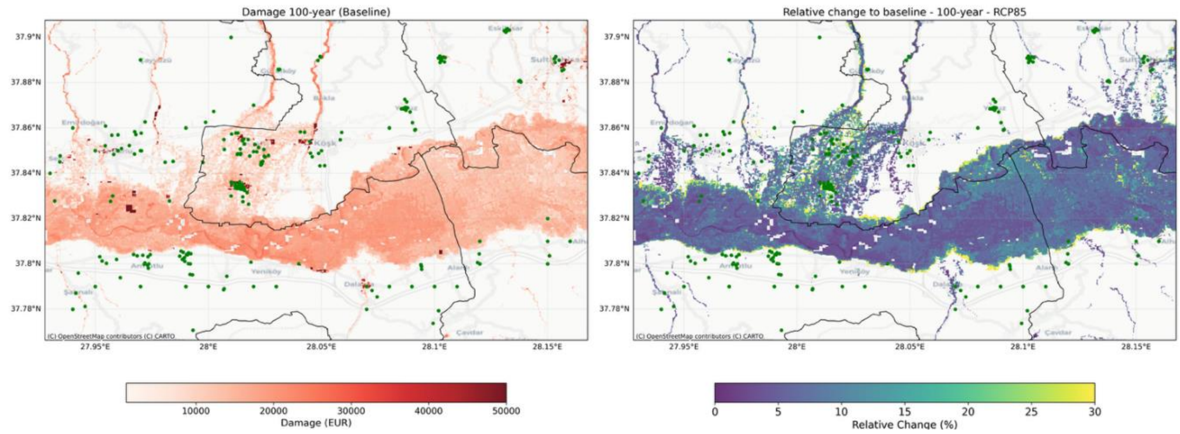

Figure 2-21 The zoomed maps of flood and associated damages for extreme river water level scenarios in current climate (left) and RCP8.5 scenario (2071-2100) for 1 in 100-year extreme event for Aydin Region.[21]

Zoomed-in analysis shows that a significant number of dairy farms in the Aydin region are situated within high-damage zones (€10k–€50k). The projected relative change under RCP8.5 indicates a widespread damage intensification of 15–25% across these farm clusters. This spatial overlap highlights a compounded risk: farms currently facing flood threats will experience deeper inundation and greater structural losses in the future. These findings underscore that flood events of the same nominal return period in the future are likely to cause deeper inundation, greater structural damage to barns and milking facilities, loss of feed and forage stocks, and increased disruption to farm access and operations.

2.3.5 Additional assessments based on local models and data

In Phase 2 of the project, hazard assessment was significantly enhanced by the integration of multiple satellite-based region-specific modeling tools. This multilayered approach allowed for the development of a more accurate and context-sensitive picture of climate-related hazards impacting

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[21] *Due to page limitations, this figure has been resized and its resolution reduced. The original high-resolution version is provided in the Annex.*

Aydin province, particularly those relevant to the dairy sector. This approach and analysis are presented in detail in the Annex.

2.4 Key Risk Assessment Findings

2.4.1 Mode of engagement for participation

The evaluation of key risks was carried out in close coordination with local stakeholders, particularly CBAA, technical personnel, and representatives from relevant provincial institutions. As outlined in Section 2.1.5, participatory processes included workshops, surveys, and bilateral consultations conducted throughout the project. Stakeholders were actively involved in identifying priority risks, validating results from the climate risk analysis, and discussing local capacities and needs.

During these engagements, participants consistently emphasized the growing impact of heatwaves and agricultural drought, both of which were perceived as severe and intensifying threats. Feedback from producers confirmed that these hazards are already disrupting dairy operations, and there is a strong demand for short- and medium-term adaptation support. Stakeholder input was instrumental in shaping both severity and urgency assessments and contributed to validating the relevance of proposed resilience strategies.

2.4.2 Gather output from Risk Analysis step

The risk evaluation builds directly upon outputs from the previous climate risk analysis phase. This includes:

- Heat-Stress Degree Days (HSDD) and Temperature-Humidity Index (THI) calculations;
- Spatial assessment of milk yield losses, fertility decline, and cooling costs under RCP8.5 scenario;
- Vulnerability mapping based on the presence of mechanical ventilation systems in dairy farms;
- District-level estimates of economic losses due to heat stress;
- Analysis of forage crop yield reductions and groundwater depletion as indicators of agricultural drought;
- Flood hazard maps and economic exposure estimates from extreme rainfall and river overflow.

These quantitative outputs were combined with qualitative insights from field visits and stakeholder feedback to determine the risk severity, urgency, and capacity to respond.

2.4.3 Assess Severity

Climate-related risks in Aydın are already moderate to high, with historical data showing recurrent extreme events that affect agricultural production, infrastructure, and livestock systems. Among these, heatwaves stand out as the most critical hazard, with a clear upward trend in frequency, duration, and intensity. Temperature-Humidity Index (THI) data reveals widespread exceedance of heat stress thresholds across all districts, leading to measurable declines in milk production, reduced fertility in dairy cattle, and escalating operational costs for cooling and ventilation.

Agricultural drought also presents a critical and compounding risk, particularly for forage production. Increasing seasonal water deficits, combined with overreliance on groundwater for irrigation, have made dairy systems highly sensitive to even moderate shifts in precipitation. Satellite-based observations (e.g., GRACE data) further indicate signs of aquifer depletion and land subsidence, suggesting a deepening structural water stress. While extreme precipitation and river flooding are somewhat more episodic, they pose substantial risks to farm infrastructure and operations—especially in low-lying or downstream areas of the Büyük Menderes Basin.

Stakeholder engagement during the CRA process confirmed these findings. Farmers and experts reported increasing constraints from both heat and water stress, including cascading impacts like feed shortages and rising disease pressure during extreme heat events. These compound risks are already reducing profitability and resilience in the dairy sector and are expected to intensify under future climate scenarios, reinforcing the need for proactive adaptation measures.

2.4.4 Assess Urgency

Dairy farms in Aydin are already experiencing the effects of heat stress, occasional flooding, and forage production pressures. Future climate projections indicate a sharp intensification of these risks. Heat stress is expected to become chronic, with rising HSDD values leading to sustained milk losses, fertility decline, and increased cooling costs. Extreme precipitation events will occur more frequently, shortening return periods and repeatedly damaging farm infrastructure. Similarly, river flooding and agricultural drought are projected to worsen, causing deeper inundations and larger economic losses.

Given these trends, heatwaves already require immediate action due to their current and future impacts. Agricultural drought and extreme precipitation demand near-term interventions, as their mid-term intensification threatens feed security and farm continuity. River flooding shows its most severe impacts in the long term (2071–2100), but due to the long lifespan of infrastructure, preventive measures must be initiated now.

Overall, the persistence and compounding nature of these hazards—particularly heat stress—underline an escalating urgency for the dairy sector. These are not temporary disruptions but long-term structural risks that demand proactive planning and sustained adaptation efforts.

2.4.5 Understand Resilience Capacity

The resilience capacity of Aydın's dairy sector is currently assessed as medium, with notable disparities across farm sizes. While some large-scale farms are equipped with mechanical ventilation, shading, and misting systems that offer protection against heat stress, these risk-reducing measures remain limited or absent in the majority of small and medium-sized farms. Based on assumptions derived from CBAA field input, approximately 20% of small, 30% of medium, and 100% of large farms are estimated to have ventilation infrastructure. This district-level approximation helped assess the proportion of livestock potentially protected from climate hazards but also exposed critical capacity gaps among more vulnerable producers.

Beyond heat adaptation, overall resilience is further challenged by dependency on groundwater, declining aquifer levels, and limited adoption of drought-resilient crops. The "2026–2028 Aydın Crop Production Plan," developed in coordination with the Provincial Drought Crisis Center, represents a positive institutional response by promoting strategic varietal and spatial crop planning. However, its implementation at the farm level remains uneven. To build robust, long-term resilience in the sector, there is a need for more inclusive investment, expanded technical support, and cross-sectoral coordination targeting both climatic and structural vulnerabilities.

2.4.6 Decide on Risk Priority

The prioritization of risks was guided by a structured evaluation framework considering severity, urgency, and resilience capacity, supported by the evaluation dashboard. Based on Figure 2-22, the following prioritization was established.

Risk Workflow	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
River flooding					High
Heavy rainfall					High
Heatwaves					Very High
Agricultural Drought					Very High

Figure 2-22 Key Risk Assessment Dashboard

Heatwaves and agricultural drought rank as the top two priorities for the region. Both exhibit high severity and increasing urgency, and while some resilience measures exist, they are insufficient in scale and distribution. These findings will directly inform recommendations for future adaptation planning, funding allocation, and technical support strategies targeting vulnerable producers in Aydin.

2.5 Monitoring and Evaluation

The second phase of the climate risk assessment delivered critical insights into how climate-related hazards manifest across space and sectors in Aydin, with a strong focus on dairy farming. By combining locally sourced data with the CLIMAAX methodology, abstract risks were translated into location-specific vulnerabilities. Integrating quantitative indicators such as THI, HSDD, and groundwater depletion with qualitative field insights from farmers and stakeholders greatly improved the assessment's accuracy and relevance. Stakeholders, especially CBAA and local authorities, played an essential role in validating findings and aligning results with real-world conditions. Despite this progress, challenges were encountered in accessing harmonized, high-resolution data—particularly at the sub-provincial scale—and in sustaining engagement with smallholder farmers due to time and resource constraints. However, the process helped build institutional and community-level awareness, and highlighted key data gaps such as real-time drought and fertility tracking, which can shape future priorities. While tools like Sentinel-5P and ERA5 datasets enhanced analysis, the need for a dedicated monitoring system tailored to the dairy sector remains. Communication of findings is ongoing through dashboards, reports, and policy engagement.

Overall, the CRA has strengthened risk awareness in Aydin and laid the groundwork for more informed adaptation planning. Its efficient use of local expertise and data allowed for broad coverage despite resource limitations, and it has helped position climate resilience as a shared priority among farmers, cooperatives, and public institutions.

2.6 Work plan Phase 3

In Phase 3, the project will focus on operationalizing the risk findings by developing a set of user-oriented outputs that directly support climate adaptation in the dairy sector. This includes the creation of a best practice guideline tailored to cattle breeders, incorporating farm-level strategies to reduce exposure to heat stress, flooding, and drought impacts. In parallel, updated hazard maps will be generated for key climate parameters, building upon the results of the risk analysis conducted in Phase 2. Risk outputs will be revised using refined socio-economic data and validated through targeted consultations with agricultural stakeholders.

The work plan will also include activities to disseminate results and foster institutional uptake, such as the organization of a regional stakeholder congress and the integration of risk information into local planning dialogues. The analysis will continue to prioritize heat stress, flood risk, and forage crop vulnerability—identified as the most urgent threats—while not expanding into unrelated sectors (e.g. urban planning or coastal zones), to maintain focus and resource efficiency. This final phase is designed to close the loop between scientific analysis, stakeholder needs, and practical action.

3 Conclusions Phase 2- Climate risk assessment

The second phase of the climate risk assessment (CRA) for the Aydin region enabled a more advanced, locally grounded understanding of how climate change affects the dairy sector. Building on the foundation of Phase 1, this stage transitioned from general vulnerability mapping to quantitative, hazard-specific risk analysis, using high-resolution local data and regionalized climate projections under RCP4.5 and RCP8.5 scenarios.

The findings clearly demonstrate that climate change poses both chronic and compounding risks for dairy farms across Aydin. Increasingly frequent and intense heatwaves, prolonged agricultural drought, and more extreme precipitation events—along with their associated flooding—are no longer future projections but observable patterns already affecting farm operations. The risk analysis incorporated key exposure and vulnerability factors, such as livestock distribution, cooling infrastructure, and the spatial arrangement of forage crop production. Despite challenges in accessing farm-level data due to confidentiality, district-level aggregation allowed for meaningful and policy-relevant results.

Key findings of the assessment include:

- Heat stress is the most immediate and widespread hazard, with Heat Stress Degree-Days (HSDD) values projected to double or triple across all districts by mid-century under RCP8.5. This will significantly reduce milk yields, impair fertility, and elevate energy costs associated with cooling systems.
- Productivity losses from heatwaves were quantified, with estimated average annual milk yield reductions reaching 250 L per cow in high-risk districts such as Didim and Söke. These impacts are expected to intensify, extending to districts previously considered less vulnerable.
- Operational cooling costs are projected to rise sharply. In central districts like Çine and Efeler, annual electricity expenditures for ventilation fans could exceed €200,000, adding to the financial strain on producers.
- Agricultural drought will increasingly threaten forage crop production, with modelled yield losses of up to 60% in central and western districts under non-irrigated conditions. When translated into revenue terms, the economic impact may reach €1.5 million annually in some districts.
- Extreme precipitation events are expected to become more frequent and intense. The historical 100 mm/24h threshold, once associated with rare storms, may become a recurrent occurrence, leading to flooding of animal housing, feed storage areas, and farm access routes.
- River flooding in the Büyük Menderes Basin will deepen under climate change. Projected inundation depths increase by 20–30% in many areas, with corresponding rises in damage to infrastructure, livestock facilities, and input supply chains.

Throughout the process, institutional engagement with local stakeholders, particularly CBAA and the Provincial Directorate of Agriculture, played a central role in identifying critical data needs and validating assumptions. While the CRA achieved a high level of technical robustness, several challenges were noted. Data limitations at the farm level restricted spatial precision. Future socio-economic trajectories were not fully integrated, as stakeholders emphasized that investment decisions remain constrained by present-day market and policy realities. Key challenges included the lack of disaggregated farm-level data, limited availability of real-time environmental indicators (e.g., soil moisture, microclimate data), and fragmented data sharing across institutions. Additionally, the absence of harmonized records on animal health and fertility limited the depth of vulnerability assessments. These challenges underscore the need for improved data infrastructure and institutional collaboration in future phases.

Nevertheless, the methodology applied—linking localized hazard projections with sector-specific exposure and vulnerability indicators—demonstrated the feasibility and value of sub-regional risk modelling for agricultural systems. The outputs of the CRA offer actionable insights to inform rural development plans, guide infrastructure investment, and support climate adaptation strategies tailored to the dairy sector in Aydin.

Looking ahead, the final phase of the project will focus on translating these findings into operational adaptation pathways. Emphasis will be placed on strengthening local capacity, integrating CRA outputs into institutional frameworks, and developing cross-sectoral dialogue on climate resilience. The CRA in Aydin provides a replicable model for other climate-sensitive regions in Türkiye and beyond, supporting long-term strategies for sustainable food systems under climate stress.

4 Progress evaluation

This deliverable marks the successful completion of the second phase of the CliResDairy project, where the climate risk assessment for Aydin's dairy sector was significantly enhanced through the integration of local data, stakeholder input, and regionalized modelling. The risk analysis covered heatwaves, agricultural drought, river flooding, and extreme precipitation, using district-level exposure and vulnerability indicators specific to dairy systems. Through targeted engagement activities, including workshops, training sessions, and scientific dissemination, the project not only strengthened the technical quality of the analysis but also ensured relevance to real-world challenges faced by farmers and institutions.

The outcomes of Phase 2 directly inform the focus of the final project phase. Key results, such as quantified milk yield and fertility losses under rising temperature scenarios, revenue risks from forage crop decline, and intensifying flood exposure, now provide the evidence base for Phase 3 activities. The upcoming phase will use these findings to produce practical outputs like risk maps and breeder guidelines, while facilitating institutional dialogue and uptake through a stakeholder congress and targeted policy engagement. A summary of the achieved milestones and performance indicators is presented in Table 4-1 and Table 4-2.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Multi-risk climate assessment successfully conducted by the end of Phase 1.	*Achieved*
Local data integration completed to refine the multi risk climate assessment by Phase 2.	*Achieved*
Climate adaptation strategy developed and implemented by the end of Phase 3.	*Phase 3*
Workshop; conducted for stakeholders, including lead farmers, policymakers, relevant agricultural organizations, sector stakeholders, and local government representatives, to increase climate risk awareness and participation.	*Achieved*
Policy Note; developed and shared with local governments to incorporate climate resilience into regional planning.	*Achieved*
Scientific Article; published based on project findings to contribute to academic research.	*Achieved*
Policy Brief; developed and shared with local governments to guide climate adaptation measures.	*Achieved*
Press Release; issued to increase public awareness and highlight project progress and results.	*Achieved*
Training Session; for agricultural consultants to enhance their capacity to support farmers in climate adaptation strategies.	*Achieved*
Stakeholder Congress; organized to disseminate the project results and foster collaboration among key participants.	*Phase 3*

Table 4-2 Overview milestones

Milestones	***Progress***
M1: Completion of the multi-risk climate assessment by the end of Month 6.	*Achieved*
M2: Successful integration of local data into the climate assessment by the end of Month 16	*Achieved*
M3: Workshop for stakeholders (including lead farmers, policymakers, agricultural organizations) completed by Month 16.	*Achieved (24 December 2025)*
M4: Training session for agricultural consultants completed by Month 16.	*Achieved (First session completed: 24 December 2025; continued)*
M5: Policy Note developed and shared with local governments by Month 16.	*Achieved (First Policy Note was published: 09 January 2026; continued)*
M6: CLIMAAX workshop in Barcelona attended in June 2025	*Achieved*
M7: Climate adaptation strategy developed and implemented by Month 22.	*Phase 3*
M8: Scientific article based on project findings submitted for publication by Month 21.	*Achieved (First article was published: 8-10 October 2025)* *At the Symposium on GeoSpatial Technologies: Visions and Horizons, held from 8–10 October 2025 at Çanakkale Onsekiz Mart University, the Cattle Breeders' Association of Aydin presented the first results of the Climate Resilience Enhancement in Dairy Farming (CliResDairy) project. Title: Climate Hazard Assessment for Dairy Farming in Aydin, Türkiye: Preliminary Results from the CliResDairy Project*
M9: Stakeholder Congress conducted by Month 21, bringing together 100 participants to discuss project results and foster collaboration.	*Phase 3*
M10: CLIMAAX workshop in Brussels attended in Dec 2026 to present final project results to policy and decision-makers.	*Phase 3*

5 Supporting documentation

The additional documents and datasets have been uploaded to the Zenodo platform *(LINK)*. The content of the files are as follows:

- Main Report (PDF)

Visual Outputs (infographics, maps, charts)

- Heavy Rainfall (extreme precipitation) Workflow (Maps and Graphs)
    - Hazard Workflow Outputs
    - Risk Assessment Outputs
- Heatwaves Workflow (Maps and Graphs)
    - Hazard Workflow (xclim) Outputs
    - Risk Assessment (climate projections) Outputs
- Agricultural Drought (Maps and Graphs)
    - Hazard Workflow Outputs
    - Risk Assessment Outputs
- River Flooding (Maps and Graphs)
    - Hazard Workflow Outputs
    - Risk Assessment Outputs
- CliResDairy Project Stakeholder Workshop Report
- Visual Documentation of Site Visits and the CliResDairy Project Stakeholder Workshop
- Communication Outputs
    - Media Coverage
    - CBAA Website Announcements
    - Social Media Dissemination

Datasets Collected

- Location of dairy farms in Aydin Region
- Aydin region boundary
- Aydin district boundary
- Historical (2024) yields of 11 crops in Aydin region
- Cattle number in dairies per district
- Ventilation fan number in dairies per district
- Aydin basin boundary
- Historical maximum daily precipitation for 2, 10, 25, 50, 100, 500 year return period
- Return Periods of 100mm precipitation threshold in Aydin based on historical observations

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